AFIT/GEE/ENY/95M-01

A DECISION MODEL FOR ENVIRONMENTAL
ASSESSMENT OF
PROCESS WASTE PRODUCTS

THESIS

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute Of Technology

In Partial Fulfillment for the Degree of

Master of Science In Engineering

and Environmental Management

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March 1995

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NTIS CRA&I		☒
DTIC TAB		☐
Unannounced		☐
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Distribution /		
Availability Codes		
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Preface

This research could not have been completed without the guidance, expertise, and support of many people. I would like to thank Dr. David Robinson, Dr. Michael Shelley, Dr. James Aldrich, Dr. Peter Torvik, Dr. Paul King, Dr. John Rusek, Mr. Raymond Hunt, Mr. Lloyd Hopper, Mr. Rudolph George, Mr. Christopher Frank, Mr George Corley, Mr. John Etheridge, and Mr. Robert Browet. I would also like to thank my wife Elena and my children Justin, Brenden, and Kathrin for their unflagging support.

Kyle Frederick Byard

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Abstract

Environmental managers must compare the potential impacts of waste products when deciding upon courses of action. The estimation and comparison of these impacts is a subjective process, and few methods of comprehensive, quantitative comparison of waste products currently exist.

The intent of this study is to develop a decision methodology to evaluate the environmental impacts of waste products and to score them for comparison. The method will follow established system design principles and incorporate significant characteristics of the waste material. Scores derived to represent the environmental impacts of materials will then be analyzed employing statistical and probabilistic methods to assess decision risk and the need for more precise information.

As an example of the method's use, it and traditional Environmental assessment (EA) methods are used to evaluate the replacement of the AIM-9 air-to-air missile with a thermoplastic missile.

Environmental Assessments of missile production, operations and maintenance, and retirement are presented. Both evaluation methods determine the thermoplastic missile to have a less negative impact than the AIM-9 in all stages. The decision methodology allows for better standardization of the analysis, quantification of the impacts, and sensitivity analysis of the characteristics of the waste materials.

I. Introduction

1.1 Background

The National Environmental Policy Act of 1969 (NEPA), requires federal agencies to take into consideration the environmental consequences of a proposed action before such action is implemented. The intent of NEPA is to protect, restore, or enhance the environment through well-informed decisions. The Council on Environmental Quality (CEQ) was established under NEPA to implement federal policy in this process and has issued regulations for implementing NEPA (40 CFR, 1500-1508). The CEQ regulations specify that an environmental assessment (EA) be prepared for a proposed action which might have a significant environmental impact. As part of this assessment, potential hazards are investigated and assigned nominal scores for comparison (CEQ;3-5).

The ability to quantify the environmental impacts of processes and use these quantities for comparisons would enhance the ability of process designers and managers to accurately evaluate the effects their decisions will have upon the quality of the environment. The use of probabilistic methods to quantify the risk of an environmental assessment would help decision makers by indicating when more information is required to make accurate comparisons.

1.2 Problem Statement

The purpose of this research is to develop a generalized methodology for comparing the environmental impacts of waste materials. The method will compare the impacts of the wastes produced by the manufacture, operation, or retirement of a system and employ probabilistic methods to characterize the risk inherent in this comparison.

Although several measures of environmental impact are currently in use by the EPA, these primarily focus on specific waste characteristics and exposure pathways. Most measures are also aimed at assessing the extent of existing damage, so as to determine the necessary remediation actions (Keller;284-5). This effort will draw these characteristics into a more comprehensive, systematic approach. The method will also allow for the comparison of dissimilar processes, since it assesses the potential harm of the waste products of the process, rather than the technical functioning of the process itself. By considering the wastes of the process, the method will account for all environmental impacts due to substances, as all materials involved in a process must be disposed of at some point and in some manner.

1.3 Scope

This research focussed on the probabilistic methods for representing the risk associated with quantifying the environmental impacts of a process and with comparing alternative options. A mathematical model for quantifying the environmental impacts of a process's waste products was created and a comparison between two alternative systems - the Viper and AIM-9 air to air missiles - was used as a demonstration of the risk assessment methods.

1.4 Methodology

To accomplish this analysis, a simple mathematical decision model was constructed to quantify the environmental impacts of process waste products. The design process for creating this model included the identification of design variables, characteristics, and user values. This model was exercised using the risk-based methodology to evaluate the waste products of two alternative missile designs. The results of this evaluation was used to demonstrate the use of probabilistic risk assessment techniques.

II. Background

2.1 National Environmental Policy Act.

The National Environmental Policy Act of 1969 (NEPA) requires all federal agencies to consider the environmental consequences of a proposed action as part of the decision making process. The intent of NEPA is to protect, restore, or enhance the environment through a well informed, systematic, inter-disciplinary approach to decision making. The Council on Environmental Quality (CEQ) was established under NEPA to implement and oversee federal policy in this process. To reach this goal, the CEQ has issued Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act (40 CFR, 1500-1508), (CEQ, 1978). These regulations specify that an environmental assessment of a proposed action be prepared. This assessment serves to briefly provide sufficient evidence and analysis for determining whether to prepare a more in-depth Environmental Impact Statement (EIS), or to make a Finding of No Significant Impact (FONSI). This Environmental Assessment typically involves a qualitative assessment of environmental impacts and their subjective scoring, rating the impacts as positive, negative, or of no consequence.

2.2 Air Force Environmental Initiatives

The Air Force is attempting to reduce the use of hazardous materials throughout the life cycle of its weapons systems. In its 1986 report Selection and Use of Hazardous and Toxic Materials in the Weapons System Development and Acquisition Process, the United States Air Force Scientific Advisory Board (SAB) found that the acquisition process did not adequately address the hazardous materials problem (Long;3).

In 1989, the Department of Defense (DOD) published Directive 4210.15 Hazardous Materials Pollution Prevention, which established the DOD policy that hazardous materials should be selected, used, and managed over the life cycle of the system, so as to avoid or reduce their use (Long;2).

Selection, use, management, and disposal of hazardous materials all focus towards a single goal; reducing the amount of waste which is ultimately returned to the environment.

2.3 Waste Factors

Subtitle C, Section 3001 of the Resource Conservation and Recovery Act (RCRA) requires the Environmental protection Agency (EPA), to identify the characteristics of hazardous wastes and to list those wastes which must be managed as hazardous (Keller;284-3).

The characteristics EPA used to make this determination were the material's "toxicity, persistence, degradability in natural conditions, potential for accumulation in tissues, flammability, corrosiveness, and other hazardous characteristics" (Keller;301-4).

2.4 Environmental Impact Models

A model is a simplified representation of an empirical situation. Ideally, it duplicates the essential behavior of a natural phenomenon with a few simply related variables. The simpler the model, the better for the decision maker, provided the model provides as a reasonably reliable representation of the empirical problem. The advantages of a simple model are its economy, the ease with which it is understood, and the ability to amke quick, efficient modifications to it. The object of the decision maker is not to construct a model which reproduces reality in every respect. Such a model would require excessive time and difficulty in its construction, and then might be to complex to use. What the decision maker wants is the simplest model that predicts outcomes reasonably well and is consistent with effective action.

After the model has been constructed, conclusions may be derived about its behavior and the decision maker bases actions on these conclusions. If relevent variables have been included in the model, in the proper form, and the logic employed in deriving conclusions from the variables is correct, then the solution of the model will also serve as an effective solution for the empirical problem (Bierman;7).

The appropriate technique for describing and relating selected variables largely depends upon the nature of those variables. Variables which are subject to measurement and quantitative representation are strong candidates for mathematical modeling. Mathematics combined with computers make it possible to use models of great complexity and facilitate the decision making process where quantitaive analysis is applicable.

Any quantitaive decision analysis, however, must be tempered by the consideration of qualitative variables. Decisions which affect human emotions, moral or social responsibilty must draw a balance between the quantitaive and the qualitative the aspects of the decision.

The majority of environmental impact models currently in use have been focused upon the physiological impacts of specific substances, or the manner in which those substances will be transported when released into a particular environment (Finkel;51).

Statistical models are frequently used to determine the likely pathways a substance may take and the levels of exposure to plants, animals, and humans which they are likely to yield. These likely exposures are then compared to toxicological data to determine the probable impacts of the contaminant upon the exposed population (Van Ekambram;43).

More specific rating scales are used to compare chemical compounds on the basis of single characteristics. Tools such as the Sax Toxicity Scale and the J.R.B. Associates Scale of Biodegradability can be easily used for comparison of substances based upon a single characteristic. Although these rating scales are useful in the examination of problems relating to these specific properties, they do not give a complete picture of a material's potential impacts and must be modified for use in more general impact assessments (Keller;277).

A more comprehensive attempt at hazard characterization is the EPA's Hazard Ranking System (HRS). This methodology assigns ordinal values to each of several substance characteristics, then uses these values to compare the potential hazards posed by the substances present at hazardous facilities. The HRS multiplies values for hazard due to toxic substance migration, fire and explosion, and direct contact. The HRS uses weighting factors to scale the estimated risk of these hazards (Keller;300-9).

Like the HRS, the Methodology for Rating the Hazard Potential for Waste Disposal Sites combines several material characteristics into an overall ordinal score which may be used to compare remediation needs. This method of rating impacts gives a more complete assessment of the problem posed by the waste substances, although it remains centered upon toxicological impacts and ignores practical considerations such as cost (Keller;301-3).

Although all of these models provide valid assessments of the characteristics of materials, they are somewhat limited in their approach to risk. Each provides only a point description of the material; a discrete score. Risk, however, is in no way so straightforward, encompassing, as it does, the realm of important information we do not know. Assessing the risk of a decision involves a wide range of possible outcomes, and must be described by a range of model results.

2.5 *Uncertainty*

All analysis contains some measure of uncertainty. No matter how well characterized a material is, there is always some portion of the data which is not known.

Uncertainty in environmental decision making arises from numerous sources. Limited data, non-representative data bases, and unknown mechanisms of action are primary causes of uncertainty in environmental affects (Shelley;6). Extrapolation of animal toxicity and exposure data to humans requires requires that numerous assumptions and "best guess" estimates be made as to how a substance's affect on animal physiology will equate to human reactions (Shelley;46). Typically, the overall impact of human exposure to a substance will be modeled through the combination of data from several different sources, using physiological systems from various animals, mathematical models, and historical studies, each of them with their own levels of uncertainty. Data from these sources is combined using estimates as to the change in the effects, moving from animals to humans and between different human populations.

Uncertainty is further compounded by the restrictions placed upon data collection by limited resources. Dose-affect and toxicology testing are expensive. Because of these high costs, simple, less-expensive methods are frequently used to screen for the highest risk factors. For example, if a test exposing a million rats to a substance for an extended period of time is needed to insure a statistical level of significance for a test, the logistical and cost problems of such a study may lead to it being redesigned as a test of a hundred rats at higher dosages. These results are then extrapolated to estimate the affect of lower doses on a larger population, and further interpreted to estimate the substance's effect on humans (Shelley;43). Even actual case data is prone to uncertainty, as the environment, conditions of collection, and other factors may make it unrepresentative of similar situations in other settings.

In the case of analysis using mathmatical models, the structure of the model being used contributes large amounts of uncertainty to the evaluation process. A single model factor, incorrectly weighted, can create greater error than the farthest outliers of variance within the factors.

Finally, there is some uncertainty inherent in all measurements and in all predictions of dependent variables from those measurements. Random variables will, by their nature, occasionally yield measurements which are not representative of typical behavior. An investigator seeking information on the height of a population would, for example, develop wholly misleading data if he began sampling as a group of basketball players or jockeys happened to be passing. Such errors happen, and inject degrees of uncertainty into the resulting relationships.

To account for this inherent uncertainty, methods have been developed to simulate the behavior of random variables and to estimate the uncertainty of relationships.

All materials and activities possess some inherent hazard in their use (Shulpein;16). Risk assessment quantifies these hazards for comparison. The risk of getting cancer from drinking chlorinated water has been estimated at 0.00008 percent. This is generally considered an acceptable hazard, when compared to drinking untreated water which may contain more hazardous contaminants which the chlorine will eliminate. In assessing the overall risk of a system which involves chlorinated water, this hazard may not have a significant impact upon the decision of how the system is managed, but it should still be identified and considered as part of the system's overall risk (Shulpein;17).

Uncertainty occurs when we measure quantities, or make predictions of dependent variables from these measurements. Engineers tend to treat such uncertainty by over designing to compensate for it (Siddall;5). In the past, environmental assessments have followed this traditional engineering design approach by incorporating "worst-case" estimates of potential damage into the risk assessment. These estimates overcome uncertainty by calculating the most extreme level of harm the situation may cause and over-designing to allow for it. This approach insures a safe decision, but does not produce realistic and useful information (Cleland-Hamnett;21).

In February of 1992, the EPA issued a memorandum on the subject of using worst-case scenarios as the basis of policy. In it, the agency emphasized the need for more accurate predictions of environmental effects, based upon more realistic situations. Such predictions should be based upon "straightforward, consistent terminology identifying uncertainties and data gaps so that both experts and citizens can more easily compare one risk to another (Cleland-Hamnett;20).

2.6 Decision Making Process in the Presence of Uncertainty

Engineering decisions are made in one of two general contexts - under conditions approaching certainty and, more commonly, under conditions of uncertainty. Decision making under conditions of certainty usually involves maximizing some objective subject to constraints. Decision making under conditions of uncertainty, when the true state of nature is unknown, involves acting with imperfect information. This is most effectively accomplished through the use of probabilities in decision analysis (Bierman;7).

Engineering design decisions have frequently been made by intuitive or experience-based means. In an attempt to improve the performance of a technical system, or the accuracy of a decision-making process, the designer moves in directions which "feel right" given his knowledge base and past experience. The basis of engineering design theory is that it should be possible to rationalize a significant amount of this decision making, basing it upon specification of values and analytical techniques (Siddall;2).

There are five general categories of ways in which decision making is used to choose the best design:

1. The Design Option Problem: Two or more "frozen" designs are compared. The performance factors are rated, and each is assigned a numerical score. This makes the decision problem a matter of determining the total value of each design and choosing the one with the highest score.

2. The Design Optimization Problem: The designer has created a general configuration in which the numerical values of the independent variables have not been fixed. To obtain the best specific configuration, the problem must be formulated by setting up a generalized decision model defining the total value in terms of the independent variables. Numerical procedures are then applied to adjust the independent variables so that expressions of constraint are satisfied.

3. The Specification Problem: Many of the constraint expressions are based upon specifications. A change in specification will change the optimum design point of what is best for the system as a whole. For example, we may wish to design the best system possible for less than $1,000,000. Or the best component which will

fit into a given space. How "best" is defined will largely depend upon the limitations the specifications place on the design.

4. The Producability Problem: Many decisions must be made in order to select the best configurations from the point of view of producability. This requires good knowledge of materials and production processes, and the decisions are made primarily on cost criteria.

5. The Risk Level Problem: A design decision as to the choice of level of risk associated with successful operation of a device. These decisions are subjective and require not only the rating of alternatives, but a method of determining the likely range of outcomes and their probability.

In solving these problems, the decision maker follows a hierarchy of design variables. At the first level are the independent design variables - the quantities the manager deals with directly at the lowest level of decision making. From these, the decision maker hopes to generate measures for the design characteristics, the second level of the hierarchy. These characteristics are qualities the manager desires to emphasize in the decision-making process. The design characteristics, in turn, generate values which have criterion associated with them. At the highest level of the hierarchy, these values are combined into an objective function. This function reflects the value criterion, while satisfying the constraints under which the decision must be made (Siddall;4).

As an example of this hierarchy, an engine designer deals with variables of shaft diameters and material yield strengths, which he hopes to use to generate measures for design characteristics such as power, torque, and weight. These characteristics are then modified in accordance with value criteria, such as maximize power, minimize cost, or minimize weight. Finally, these values are combined into a unified objective function for the system, which may be optimized to best satisfy the value criteria. If the designer is seeking the most powerful engine possible, regardless of cost, size, weight, or fuel consumption, the function will optimize the single characteristic of power. Alternatively, as the other characteristics are given increased value, the power of the design may fall, but the overall system will be optimized.

To deal with uncertainty in this process it must somehow be measured. One measurement of uncertainty may be the probability of an event or outcome. If the variables in a function are assumed to occur randomly, then the probability of an outcome can be estimated through repeated trials of the function (Siddall;11).

2.7 Elementary Concepts in Modeling and Design

The basic goal of engineering design is to develop, in response to human needs, physical systems which represent the optimum economic balance between cost and risk. Demands are increasing for high performance products which are reliable, safe, and cost effective. Furthermore, shortages in world and national resources have accelerated this demand for quality. Recent developments in many fields promise to provide engineers with tools by which they can substantially improve the quality of mechanical and structural design. Some of these new tools include:

1. Finite element analysis (improved methods of computing stresses).

2. Better descriptions of material behavior, e.g., fatigue, creep, high strain rate properties, etc.

3. Fracture mechanics (crack propagation models to describe brittle fracture and fatigue).

4. Optimization theory

5. New materials, metals, plastics, filamentary composites, etc. for use by designers.

6. New digital computers and electronic calculators.

7. Methodology for the application of probability and mathematical statistics to design theory.

Close scrutiny of a typical design problem reveals a process made extremely complicated by the many uncertainties that exist in the design factors. These uncertainties may be characterized as two types:

Statistical Uncertainty: This includes design factors which, by experiment, are observed to be physically random. For example, factors such as yield strength, tolerances, and wind gusts, all of which impact upon system performance and can only be roughly predicted. The results of such observations are usually presented as sample means and standard deviations, histograms, etc. This type of uncertainty is inherent because it is an organic characteristic of the data.

Nonstatistical Uncertainty: (Also called "professional uncertainty", "subjective uncertainty", or "modeling error") includes uncertainty introduced by the many simplifying assumptions which must be made in static and/or dynamic analysis, as well as assumptions which must be made when knowledge is lacking regarding design factors which would ordinarily be statistical. In principle, this uncertainty can be reduced by further sampling or model refinement (Robinson; 1990).

Two important sources of error in using models for decision making are the exclusion of important variables and mistakes in defining relationships among the variables. In either of these cases, the model may not represent the actual state of nature adequately enough for decision purposes. A significant failure in one of these areas may flaw the model far beyond the effects of any possible variances in the data used (Bierman;7).

2.8 The Working Stress Approach to Uncertainty

Traditionally, the analyst assumes loading on an element to be single valued and equal to some "maximum anticipated" or nominal value S_0. Similarly, the strength of the element is assumed deterministic and equal to some value R_0. A single factor of safety, n>1, arbitrarily chosen, accounts for all of the uncertainty in the problem. The system is considered to be safe if $S_0 \leq R_0/n$. R_0/n is the maximum allowable stress and is called the "working stress". The advantage of this algorithm is that it is easy to use, but the major disadvantage is that, by its very nature, it tends to consistently yield overly conservative results.

2.9 The Probabilistic Design Approach to Uncertainty

"Probabilistic design" is proposed as an alternative to the conventional working stress approach. Each factor in the process, regardless of whether it is statistical or nonstatistical, can be defined and treated as a random variable. (Considering the goal of decision making, the distinction between objective and subjective uncertainty is irrelevant.)

Using methodology from probabilistic theory, the analyst develops the appropriate model and computes the probability of f or p_f. The basic design requirement is that $p_f < p_o$, where p_o is the maximum allowable risk. Clearly the probabilistic approach is more difficult to apply and, in widespread use, this can be a hindrance. Industry generally prefers probability-based design codes simple enough for use by the average worker.

Given an infinite supply of resources, deterministic descriptions of complicated physical processes could be developed, e.g. the occurrence and magnitude of earthquake motions. However, as an alternative, the engineer can use statistical methods as convenient tools to describe, or model, physical phenomena too complex to treat with the present level of scientific knowledge.

It has been widely accepted that probabilistic design procedures promise to improve the quality of engineered systems for the following reasons:

1. Most design factors such as applied forces, materials strength, geometry, etc. posses significant statistical variability. Probabilistic design incorporates given statistical data explicitly into the design algorithms. Conventional design discards such data.

2. It is more meaningful to say, "This system has a probability of 10^{-4} of failing after 1,000 hours of operation," than to say, "This system has a factor of safety of 2.3." Probabilistic design uses minimum allowable reliability as the basic design criterion.

3. Because the risk, p_f is a more meaningful description of structural performance, rational comparisons can be made between two or more competing designs for a proposed system. In the absence of other considerations the engineer chooses the design having the lowest p_f.

4. By treating each nonstatistical uncertainty as a random variable, its effect on the final design can be quantified. A manager can balance the cost of conducting a research program to remove this uncertainty with the payoff associated with removing the uncertainty and improving the risk.

5. Probabilistic based information on performance can be used to develop rational policies towards policies and procedures.

2.10 The Cost of Overdesign

It has been suggested that risk based procedures promise to provide more efficient models than the conventional approach. Traditional methods tend to result in overdesigned systems. The central question is "what is the cost of applying excessive safety margins in the decision process?" As yet, a satisfactory answer does not exist, but some preliminary studies have indicated that such costs may be considerable. It has been suggested that the savings in material realized by "efficient" modeling methods may be 10 to 25%.

2.11 Life Cycle of a System

The lifetime of a system can be assessed in three distinct phases: Production, Operations and Maintenance, and Retirement (USAF;2-4).

Production includes those activities which begin with the arrival of the raw material at the manufacturing facility and end with the shipment of the finished components to the user (Long:2-13). Operations and Maintenance is defined as those activities performed by the user as an expected part of the normal use and repair of the system, necessary to its intended use. Retirement includes those actions taken when the system is no longer suitable for use (Long:2-13). In an air-to-air missile system, retirement takes place when the missile is fired from its launch platform, becomes damaged during handling, exceeds its "shelf life" in storage, or no longer satisfies operational requirements.

Each of these stages in the life cycle are distinct, do not overlap, and are under the ownership of different agencies within the Air Force. As the system progresses from one stage to the next, it is "handed off" from one user to another and operates in different environments. It is, therefore, logical to assess the environmental impact of each of these stages separately.

III. Methodology

3.1 Introduction This chapter describes the research methodology used to construct a generalized decision model which will score the environmental impacts of waste substances. The construction of this function will follow the analytical decision making process:

1. Define the independent design variables.
2. Relate these variables into design characteristics.
3. Consider these characteristics in terms of criterion values and system constraints.
4. Combine these values into an objective function.

Data on the specific wastes of the Viper and AIM-9 missiles will then be gathered and the results used to score the respective products throughout their life cycles.

Finally, probabilistic methods will be applied in order to characterize the risk associated with a decision made, based upon the results of the model.

3.2 Define the Independent Design Variables

3.2.1 Independent Variables of Waste

RCRA defines a waste as any material which is disposed of, burned or incinerated, or recycled. RCRA also considers any material accumulated, stored, or treated before or in lieu of being disposed of, burned, or incinerated as a waste (Keller;284-5).

The variables pertaining to these wastes are the physical properties of the substances, such as their acidity, solubility, rate of absorption by tissue, radioactivity, carcinogenicity, biodegradability, and lethal dosage (Keller;302-1). In and of themselves, these characteristics tell us little, however, significant work has been done in converting data on these raw variables into usable substance characteristics.

This model will evaluate only the waste products of a process, as these will be the substances entering the environment. All materials used in a process must, at some point and in some manner, be disposed of and become waste, so considering waste products in the evaluation allows for complete accounting of the materials used in a process without repeat counting of them. The environmental hazard posed by these waste materials will be determined by several characteristics.

3.2.2 Toxicity

Toxicity is the ability of a material to produce injury or disease upon exposure to a living organism. (Wagner 36). Toxicity has been determined through extensive study of exposure. These studies involve actual human exposures, animal exposures, and mathematical models (Kalos;301-5).

The Sax Toxicity Scale, used by the EPA, considers a wide range of substance variables in assigning ordinal ratings reflecting its degree of hazard to humans. These include its mobility, absorption in tissue, and lethality (Lewis;16).

3.2.3 Persistence

The persistence of a substance is a measure of its biodegradability. Under normal environmental conditions, what is the expected life time of the material before it decomposes? The EPA Hazard Ranking System considers persistence as a negative characteristic of a material, because the more persistent the material, the longer lived the hazard it presents (Keller;284-5). Although the chemical stability persistence represents may also decrease the volatility of the material, it is the continuation of the hazard which is considered most significant by the EPA..

3.2.4 Cost of Remediation

The National Oil and Hazardous Substances Pollution Contingency Plan lists the cost of installing or implementing remedial action as a determining factor in the selection of remediation alternatives (Keller;302-4). Costs for remediation of contaminated sites can be staggering. A 1988 study of 36 CERCLA site cleanup projects revealed an average capital cost for remedial actions of $ 5.619 million, with the largest percentage of the sites falling in the $1 million to $3 million range (Haiges;29). Cost was one of the nine criteria for evaluation of CERCLA sites (Haiges;31). The cost of remediation for a release site is affected by the substance's mobility, soil absorption characteristics, solubility, lethality, ability to be absorbed by tissue, location, and other variables. The characteristics of the waste will, therefore, have a direct impact upon the cost of cleaning the material up, should it be accidentally released during use and that cost will be a significant measure of the risk being incurred by the creation of the waste.

3.2.5 Recyclability

In hazardous waste management practice and in the RCRA regulations, recycling refers to the effective use or reuse of a waste as a substitute for a commercial product, or as an ingredient in an industrial process (Blackman;37). Recycling implies use, reuse, or reclamation of a waste after it is generated by a process (CRS;57).

3.2.6 Amount

Virtually all regulations of pollutants are referenced to the amount of the pollutant in question. Toxicological studies, cleanup estimates, reporting requirements, and status as a waste producer or transporter all depend directly upon the amount of the pollutant in question. The Hazard Rating Scale incorporates the weight of pollutant present in its concentration computations (Keller;284-5).

3.3 Relate These Variables into Design Characteristics

3.3.1 Introduction Once the variables to be considered have been identified, they must be measured or characterized in such a manner as to have meaning to the decision maker. This is the process of using the design variables, the most basic quantities the decision maker deals with, to generate design characteristics; quantities upon which the model can be based.

Applying the decision making process, materials being evaluated for potential impact upon the environment will be examined on the basis of their variables of toxicity, amount, remediation cost, persitance, and recyclability. To conduct this examination, we must have some method of measuring, or characterizing, these variables. Once a basis for measuring these variables has been adopted, they are then suited for comparison (Siddall;4).

3.3.2 Reportable Quantity

The variables of toxicity and amount are independent as variables in an equation, but not so in the manner in which we assess their importance. The greater the toxicity of a substance, the greater is our concern for an amount of it. This relationship must be accounted for in any decision model assessing the environmental impact of a substance. After several attempts to use seperate measurements for these variables and to account for the relationship between them in the later stages of model development, it was decided that the most effective method of measuring toxicity and amount was by using the combined measure of Reportable Quantity (RQ) (Keller;284-5).

CERCLA identifies approximately 720 hazardous substances and the quantities of these materials which will require reporting of its release. These

Reportable Quantities (RQ) are established by the EPA based upon the substance's intrinsic physical, chemical, and toxicological properties. These properties include aquatic toxicity, mammalian toxicity, ignitability, reactivity, chronic toxicity, and potential carcinogenicity. EPA ranks each intrinsic property (except for carcinogenicity potential) on a five-tier scale that has an RQ level for each tier. The scale uses RQ levels of 1, 10, 100, 1000, and 5000 pounds. These levels were previously established by the Clean Water Act (44FR 50776, August 29, 1979). Each substance is evaluated for its carcinogenicity potential. A high, medium, or low carcinogenicity potential receives a corresponding RQ level of 1, 10, or 100 pounds. At the end of this ranking process, a substance is assigned the lowest RQ from the evaluations, provided that the RQ is protective of human health and the environment. When an RQ has not been assigned to a substance, EPA assumes an RQ of 100 lbs. until a formal analysis can be conducted (Wagner;275). Toxicity and amount were accounted for indirectly through the Reportable Quantity. By using the RQ, the model is able to account for the characteristic of toxicity, as well as the ignitability, reactivity, chronic toxicity, and potential carcinogenicity. Using RQ as the unit of measurement for the waste, rather than raw weight, ties the amount to the severity of the hazard. Using RQ in this way insures proportionality between wastes. The function, therefore, considered the amount of a waste by calculating the multiples of the Reportable Quantity produced.

3.3.3 Cost of Remediation

The cost of remediation was scored on a 5 point scale using the values developed in the survey of superfund cleanup which produced a logarithmic scale Haiges;22-33). The scale rated the estimated cost of complete remediation of an accidental release of 50% of the annual volume of waste produced, if the release occurred in the normal use and storage environment of the waste. The 50% level was an estimate of a worst case scenario based upon questioning of several manufacturing environmental managers and reflects the reality that, in an ongoing manufacturing, maintenance, or disposal process, waste is processed as part of the system. This means the entire quantity of a waste produced will almost never be in one place at one time and therefore vulnerable to a 100% spill.

Table 1:Remediation Cost

Rating	Cost
1	< $ 10,000
2	$ 10,000 <> $ 100,000
3	$ 100,000 <> $ 1,000,000
4	$ 1,000,000 <> 5,000,000
5	$ 10,000,000

The "hidden" costs of producing waste (regulatory compliance, health care, insurance, storage) are - for the purposes of this function - considered separately from the cost of the environmental impact of the process, as they will be accounted for under the operating costs of the process. These costs are considered by the decision makers directly when determining the economic viability of the process.

The cost of remediation will be treated as an independent variable. Although the toxicity and amount of the spilled substance have some small affect upon the cost of cleaning up an accidental release, this is far outweighed by political considerations of the regulatory authorities and the perceived risk by the community (Browet;1994).

3.3.4 Recyclability

The recyclability of the waste was rated on a four tiered scale based upon interviews with manufacturers and site cleanup managers. These managers were questioned as to the variables which determined the recyclability of a waste material. The identified characteristics of cost and ease of processing were combined into the four general levels of recyclability.

Table 2: Recyclability Characteristics

Ratings	Characteristics
1	Material cannot be practically recycled.
2	Material can be recycled at significant cost.
3	Material can be recycled without significant cost or profit.
4	Material can be recycled, yielding a savings, or sold to commercial recylers.

The 1 to 4 value scale was applied to place recyclability in equal standing, in the model, with persistance and cost. The actual weighting of these characteristics is a value and will be unique to each decsion maker and situation. Given this unpredictability, the characteristics were assigned equal weighting to render them value neutral.

Since the degree of recyclability reduces the impact of the waste, it must be accounted for in a manner which lowers the material's score proportionally to its recyclability.

3.3.5 Persistance

The EPA rates the persistence of substances on a four tiered scale:

Table 3: Persistence Characteristics (Keller;302-5)

Rating	Substance Characteristics
0	Easily Biodegradable Compounds
1	Straight Chain Hydrocarbons
2	Substituted and Other Ring Compounds
3	Metals, Polycyclic Compounds

This scale uses the chemical structure of the material to broadly categorize it into one of four groups, depending upon the estimated length of time it will remain in the environment if disposed of without treatment. For the purposes of this model, the scale will be altered to assign scores from 1 to 4, instead of from 0 to 3. This will allow for the multiplication of scores without a zero factor.

3.4 Consider These Characteristics in Terms of Criterion Values

3.4.1 Introduction While material characteristics provide meaningful information about a substance, it is how these characteristics relate to our system of values which guides our decisions. Measuring the cost of an action only has meaning when we place a value on money. If our funds are unlimited, the measurement of monetary cost will have no bearing on our decision. Once a set of characteristics has been developed for a substance, it is left to the decision maker to determine which characteristics to emphasize and optimize and which to ignore.

Current regulations, laws, and assessment systems place the highest value on human health and safety. The guiding criteria for most environmental regulation is preventing human exposure to potentially hazardous amounts of materials (Cleland;21).

Protection of the physical environment and minimization of cost are "second tier" values reflected in government and industry policy. Once human safety has been safe guarded, activities such as recycling and the replacement of persistent materials are encouraged and rewarded. The use of Chloroflorocarbons (CFCs), for example, is known to cause significant harm to the atmosphere. Unfortunately, these substances have been critical to refrigeration, air conditioning, and fire suppression systems. Government policy towards the environment has been willing to accept the damage CFCs cause, in grudging preference to the health hazards of unrefrigerated food, uncooled buildings in deserts, and human work areas (primarily aircraft) without fire control systems. This is not to say the government has turned its back on the use of CFCs, but it has chosen, in its value system, to reward replacement of these materials and to punish their expanded use. These rewards tend to come in the form of economic rewards and penalties; subsidies for desired behavior, licensing fees, fines, and law suits for undesired actions (Finkel;51).

Government regulations seek to protect the health of the population through the control and reduction of the amounts and toxicities of materials used in commercial systems. Protection of the environment is also served by these actions, and is furthered by the aggressive promotion of recycling.

The cost of remediation of material spills is also subject to government regulation, in that numerous statutes impose monetary fines upon users who allow such spills to happen. Federal tort laws also allow individuals who have suffered adverse effects from such spills to collect damages from those responsible. Since very few decision makers operate with unlimited funds, it is clear we should accept the minimzation of cost as a value of most decision makers.

These values are reflected in the relationships currently used to meausre environmental characteristics. As the amount of a substance increases, the impact of that substance also increases. This is not only intuitively obvious, but is reflected in the concentration calculations, the Hazard Rating Scale, and the Dispersing Effectiveness Tests used by EPA (Keller;284-5). The greater the amount of the pollutant, the higher the level of exposure, and the more pronounced the impact.

As the toxicity of a material increases, its degree of hazard increases. Again, this relationship is a basic assumption of all exposure and environmental risk models. Since toxicity is defined as the ability of the material to produce injury or disease, the greater this ability, the greater the potential impact of the substance.

For this model, toxicity and volume have been combined into the measurement of numbers of reportable quantities. These relationships, however, are consistent with minimization of the numbers of RQ, as reducing either the volume or the toxicity of the material will reduce the number of RQ present.

The longer the persistence of a material, the greater its impact on the environment. As earlier stated, persistence may provide some benefits when viewed as stability, but EPA determined, in its Hazard Rating Scale, that the persistence of a substance significantly increased the hazard that material posed. The HRS quantified this increase by rating persistence on a scale of 0 to 3, then multiplying the substance's toxicity by a factor of zero to three for each level of its persistence, creating a scale of multiples of 3 from 0 to 18 (Keller;300-38).

The greater the recyclability of a substance, the smaller will be its impact upon the environment if it is recycled. This relationship is established in the

Pollution Prevention Act of 1990, which authorized the EPA to provide matching funds to states which establish technical assistance programs to promote recycling (CRS;54). Recycling uses waste material which would otherwise need to be disposed of in the environment. Recycling reduces the impact of a substance.

Interviews of manufacturers and site cleanup managers for thermoplastic and metal systems identified ease and expense as the primary characteristics determining a material's likelihood to be recycled. A material which requires significant expense or processing to recycle is more likely to be disposed of in a land fill or incinerated.

In summary, the values included in the objective function, therefore, are the minimization of persistence, cost, and the number of reportable quantities, and the maximization of recyclability.

3.5 Combine These Characteristics into an Objective Function

3.5.1 Model Development

Once the material characteristics and the values guiding decision making are determined, a function is developed to provide an indication of the environmental impacts of a waste material. This objective function allows for the simultaneous consideration of all major variables in the decision process (Siddall;5).

As with all measurements, the results of this model are subject to uncertainty. Questioning of the environmental managers for the subject processes yielded expected possible variances for the material characteristics, given the likely ranges of output. A series of 1,000 trials was conducted using random variations about the expected value for each characteristic of the waste products produced in a manufacturing process. This series of trials yielded a probability distribution of the likelihood that the model will yield a particular result, allowing a comparison to be made with consideration for model and parameter uncertainty.

3.5.2 The Decision Making Model

The central question considered in developing the decision model is how to rank order a wide range of dissimilar substances and be reasonably assured this ranking places them in their proper order. Reliably evaluating this function would give environmental decision makers a useful tool for evaluating alternatives.

Even with the measurable characteristics and criterion values defined earlier, this ranking remains a highly subjective process. How the characteristics affect the decision maker is strongly dependent upon the hierarchy of values that person uses in their decision criteria. Cost and persistence are particularly troublesome when trying to produce standardized criteria, since the importance of these is largely in the eye of the beholder and in the context of the situation. For example, the cost of removing and disposing of a highly persistent, slightly toxic solid substance will have significantly different weight in the decision making process if it is located in a restricted area in the Nevada desert, as opposed to a crowded neighborhood. A barrel of DDT buried in a field may make one person sleepless with the fear of the harm it will cause, over its long lifetime, while another quakes at the thought of the cost of finding and disposing of it. Reducing cost and persistence to a common measure also proved unsuccessful, as persistence - by its nature - involves periods of time and cost and fluctuates wildly with unforeseeable changes in technology and economic conditions.

Given the largely unquantifiable nature of the relationships between the characteristics, relating them took the simplest path, giving them equal weight. Cost (C), Persistence (P), and Numbers of Reportable Quantities (N) were multiplied together, insuring they were directly proportional to the final score, with their product divided by the Recyclability (R) of the substance. This relationship insured that the score reflected the basic relationships of cost, persistence, amount, and toxicity (the last two combined in numbers of reportable quantities) as magnifying each other's importance, while the ability to recycle the substance, and remove it from the waste stream, decreased the importance of each.

Cost of remediation as an equal variable is also supported by the survey of superfund clean up sites, which identified cost as a primary factor in determining the course of remediation action and established an amplifying effect of cost on other varibles (Haiges;18).

Combining these varibles in the manner described suggested the relationship:

$$\text{Material Impact Rating} = (NCP/R) \qquad (1)$$

Table 4: Model Varibles

N	Number of reportable quantities of waste produced.
P	Persistence of the waste.
C	Cost of Cleanup if the waste were accidentally spilled.
R	Recyclability of the waste.

This equation yields a rating for an individual waste product. To achieve a score for an entire process, these individual waste ratings are summed, yielding the process impact rating equation:

$$\text{Process Score} = \Sigma(N_i C_i P_i / R_i) \qquad (2)$$

As a demonstration of this relationship, high, medium, and low values for each characteristic were selected and combined repeatedly to produce a scale of possible scores. These test values are shown in table 5. This scale allowed for the qualitative assessment of the rating system, insuring certain combinations of varibles did not produce illogical results. The characteristic of Number of Reportable Quantities has no finite upper limit, as do the other characteristics. A value of 100 reportable quantities was chosen as the high value for that characteristic, as it is an order of magnitude above the medium value of ten RQ. The low value of a single RQ is an order of magnitude below the median. The results of this test are depicted in table 6.

Table 5: Test Values for Substance Characteristics

	Number of RQ	Persistence	Cost	Recyclability
High	100	4	5	4
Medium	10	2	3	2
Low	1	1	1	1

Table 6: Test Values

	N	P	C	R	Score
1	100	4	5	1	2000.00
2	100	4	3	1	1200.00
3	100	4	5	2	1000.00
4	100	2	5	1	1000.00
5	100	4	3	2	600.00
6	100	2	3	1	600.00
7	100	4	5	4	500.00
8	100	2	5	2	500.00
9	100	1	5	1	500.00
10	100	4	1	1	400.00
11	100	4	3	4	300.00
12	100	2	3	2	300.00
13	100	1	3	1	300.00
14	100	2	5	4	250.00
15	100	1	5	2	250.00
16	10	4	5	1	200.00
17	100	4	1	2	200.00
18	100	2	1	1	200.00
19	100	2	3	4	150.00
20	100	1	3	2	150.00
21	100	1	5	4	125.00
22	10	4	3	1	120.00
23	10	4	5	2	100.00
24	10	2	5	1	100.00
25	100	4	1	4	100.00
26	100	2	1	2	100.00
27	100	1	1	1	100.00
28	100	1	3	4	75.00
29	10	4	3	2	60.00
30	10	2	3	1	60.00
31	10	4	5	4	50.00
32	10	2	5	2	50.00
33	10	1	5	1	50.00
34	100	2	1	4	50.00
35	100	1	1	2	50.00
36	10	4	1	1	40.00
37	10	4	3	4	30.00
38	10	2	3	2	30.00
39	10	1	3	1	30.00
40	10	2	5	4	25.00
41	10	1	5	2	25.00
42	100	1	1	4	25.00
43	1	4	5	1	20.00
44	10	4	1	2	20.00
45	10	2	1	1	20.00
46	10	2	3	4	15.00
47	10	1	3	2	15.00
48	10	1	5	4	12.50
49	1	4	3	1	12.00
50	1	4	5	2	10.00
51	1	2	5	1	10.00
52	10	4	1	4	10.00
53	10	2	1	2	10.00
54	10	1	1	1	10.00
55	10	1	3	4	7.50
56	1	4	3	2	6.00
57	1	2	3	1	6.00
58	1	4	5	4	5.00
59	1	2	5	2	5.00
60	1	1	5	1	5.00
61	10	2	1	4	5.00
62	10	1	1	2	5.00
63	1	4	1	1	4.00
64	1	4	3	4	3.00
65	1	2	3	2	3.00
66	1	1	3	1	3.00
67	1	2	5	4	2.50
68	1	1	5	2	2.50
69	10	1	1	4	2.50
70	1	4	1	2	2.00
71	1	2	1	1	2.00
72	1	2	3	4	1.50
73	1	1	3	2	1.50
74	1	1	5	4	1.25
75	1	4	1	4	1.00
76	1	2	1	2	1.00
77	1	1	1	1	1.00
78	1	1	3	4	0.75
79	1	2	1	4	0.50
80	1	1	1	2	0.50
81	1	1	1	4	0.25

As points of reference, 1,000 pounds of a toxic, highly persistent, non recyclable substance, such as a Polychlorinated Biphenyl (PCB) would have characteristic values of 100 times RQ, 4 for persistence, and 1 for recyclability. Spread in a populated area in a highly mobile liquid form, 50% of this material would be expensive to clean up, easily approaching a million dollars, if the area of contamination was not too widespread. This would be a cost score of 3. This situation would be represented by the values in line 2 of the test table and the scoring calculation ([100 x 4 x 3]/1) would yield a score of 1,200. Ten pounds of Dichlorodiphenyl Trichloroethane (DDT) would have characteristic values of 10 times RQ, persistence of 4, and a recyclability of 1. In a drum in a secure and well contained storage area, a spill of 50% of this substance would be removed at significantly lower cost (cost score of 1). This situation would be represented by line 10 in the test table with a score ([10 x 4 x 1]/1) of 40. While DDT has a lower RQ than PCB, the setting of these situations would make the DDT less expensive to clean up, were it released. Moving the DDT out of the storage area, where environmental regulations would make its clean up simpler and cheaper, and placing it in the neighborhood with the PCB would drive its remediation cost - and therefore its score - up. On the low end of the scale, line 75 (persistence = 4, cost = 1, recyclability = 4, number RQ = 1) would be typical of the values for a 5,000 pound aluminum piece of machinery located on a factory floor. It is very persistent and, left to time and the elements, the factory might well crumble to dust and leave the machinery more or less intact. But the cost of cleaning up this aluminum is minimal and the metal may be sold to commercial recycling operations, so its score ([1 x 4 x 1]/4) is a very small 1.0.

This is not to say that 100 pounds of PCB in a populated neighborhood is 1,200 times worse than 5,000 pounds of aluminum in a factory, but it would indicate to the decision maker that - from an environmental standpoint - the process which produces the aluminum waste is preferable to a process which produces the PCB.

Near the center of the test table, the scores become closer and we would expect the decisions they represent to become more difficult. For example, 10,000 lbs. of methane (persistence = 1, cost = 2, recyclability = 4, number RQ = 10) and 10,000 lbs. of acetic acid (persistence = 1, cost = 1, recyclability = 2, number RQ = 10) would both rate scores of 5.0 in a regulated environment. Although the methane is more easily and economically recycled than the acetic acid, the latter is less persistent. Which is preferable as a waste product is purely a judgment call by the decision maker, depending upon his or her value system. A decision maker very concerned with the bottom line may choose the methane because of the possibility of reducing costs by selling the waste product. However, a decision maker concerned with the possibility of long term liability if pollutants contaminate their workplace may prefer the less persistent acetic acid. In this case, the model cannot indicate preference, only the different variables for each of the equally scored substances.

3.5.4 Characterizing Uncertainty

The overall uncertainty in the decision model may be predicted, since the score for each waste product is the result of a parametric relationship among random variables (Siddall; 341). The decision maker needs to know the amount of risk he or she is incurring in trusting the ordering of waste products by the model.

The distribution commonly used in uncertainty analysis is the Weibull Probability Density Function (PDF) The justification for its use is based more on convenience and custom than on strong experimental evidence (Siddall;358). In any case, the Weibull function is certainly a candidate for representing the results of the decision model and will be used in estimating the model's uncertainty because it offers both simplicity and flexibility. Therefore, N_i, P_i, R_i, and C_i are each assumed to Weibully distributed random variables. Estimates of the mean and coefficient of variation can be assumed for each of these random variables based upon historical evidence. From these, the unique values for the PDF shape and scale parameters, b and h can be estimated. A complete description of the PDF permits the generation of random samples for values of N_i, P_i, R_i, and C_i for each waste product.

3.5.5 Weibull Distribution

The Weibull cumulative density function is defined by:

$$F(x) = 1 - \exp[-(x/\eta)^{\beta}] \quad (3)$$

Where η and β are the scale and shape parameters, respectively, and moments are defined:

$$E(x^{n}) = \eta^{n} \quad \Gamma(x/\beta + 1) \quad (4)$$

Therefore, the mean (n=1) is:

$$\mu = \eta \, \Gamma(1/\beta + 1) \quad (5)$$

and the coefficient of variation is:

$$C = [\Gamma(2/\beta + 1)/\Gamma^{2}(1/\beta + 1)]^{1/2} \quad (6)$$

Because these equations are extremely difficult to solve, engineers typically make the approximation

$$\beta = C^{-1.08} \quad (7)$$

For example, a substance is scored, with ratings assigned for each of the four material characteristics. These ratings are assumed to be mean values of the range of scores which those characteristics might actually have. However, there is some uncertainty inherent in assigning a discrete score to this characteristic. The rating is then examined for how confident the evaluator feels is that it is an accurate reflection of reality. For example, the evaluator who assigned the persistence rating of 3 may estimate that it could be as high as 3.5, or as low as 2.7. This potential range of scores may be used to estimate the associated coefficient of variation:

$$C = \frac{\text{Score}_{max} - \text{Score}_{min}}{\text{Average Score}} \tag{8}$$

In the case of the persistence rating, this calculation would be

$$C = \frac{3.5 - 2.7}{3} = .267 \tag{9}$$

Given the estimates for the mean μ and C, the shape and scale parameters can be calculated.

Now that each of the decision variables can be completely described with a Weibull PDF, a Monte Carlo simulation of the decision model can be accomplished. Using the general scoring function

$$\text{Substance Score} = N_i C_i P_i / R_i \tag{10}$$

random values for each of the characteristics are generated from individual Weibull PDFs for each of the n substances. These random deviates are then input into the scoring function, and an overall score is produced. This process is repeated for 1,000 trials, each trial having a random combination of $N_i C_i P_i / R_i$. Since each of these characteristics are random variables, the score which results from them will also be a random variable and will have its own PDF. An example using a single substance is shown in table 7.

Table 7: PDF Generation

Trial	N_1	C_1	P_1	R_1	$N_iC_iP_i$ $/R_i$
1	2	1	3	4	1.5
2	2.1	.8	2.9	3.8	1.28
3	1.9	1.1	2.9	3.8	1.59
↓					
n	2.2	1.2	2.8	4.0	1.85

A sample of one such comparison is provided in Figure 1. In this case, the comparison is made between operations and maintenance (O&M) procedures for the AIM-9 air-to-air missile and the proposed Viper missile. Scoring of these processes is provided in Section V.

The PDFs for the respective options display markedly different shapes and ranges. The Viper estimated mean score is lower because the missile eliminates the use of many of the solvents and paints currently used for resurfacing the AIM-9. The Viper PDF is spiked and covers a small range of potential values because there is little uncertainty involved in the types and volumes of the wastes produced by Viper maintenance. The AIM-9, in contrast, displays a PDF with a wide range of potential values. This difference is due to the greater number of AIM-9 waste products and the wide variation in possible volume of them. Painting is the primary generator of AIM-9 O&M uncertainty. The solvents used for stripping the damaged and worn paint from the missile have low reportable quantities and vary significantly from year to year, depending upon the wear experienced by the missile. This variation may cause large changes in the number of reportable quantities and, therefore, in the overall score of the process.

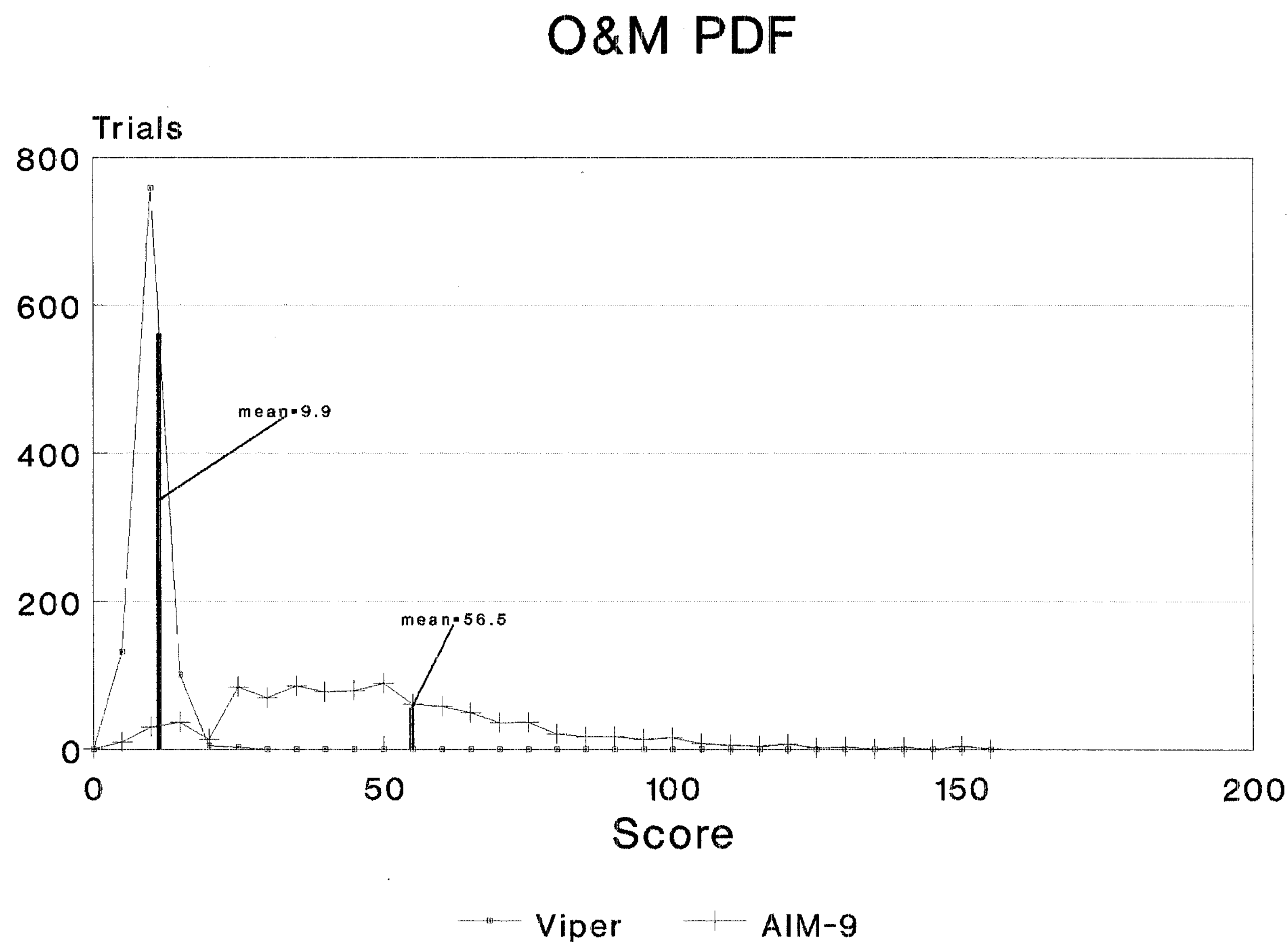

Figure 1. Operations & Maintenance PDF

Where the PDFs overlap, there exists the decision maker's risk of making an incorrect choice between the two alternatives. In this case, this risk exists if the Viper score is, in reality, in the far right tail of its PDF and the actual score of the AIM-9 is in the far left tail of its PDF. This situation would require simultaneously large variations of both process scores from their estimated means.

3.6 Data Collection In order to exercise the method using the AIM-9 and Viper, it was necessary to develop data on the waste products of each system throughout their respective life cycles. The sources for this information were the environmental managers for production, maintenance, and retirement facilities used by the current missile and likely to be used by its replacement.

Production information was gathered from the Hercules Corporation, manufacturer of the AIM-9, and from the Accutech Corporation and Air Force Advanced Composites Program Office, manufacturers of injection molded thermoplastics similar to those which will be used in the Viper. Hercules produces approximately 1,500 AIM-9 missiles annually, and this number was used to determine waste quantities for both systems.

Maintenance data was obtained from the 906 Tactical Fighter Group, Wright-Patterson AFB, OH. This unit is a user of the current system and would be a user of its replacement. This unit served as a model for system operations and maintenance and values for use, inventory levels, and other input variables for both systems were taken from it. The 906 TFG maintains an inventory of 16 AIM-9s, and this number was used as the baseline for inventory for both systems.

Data on the process of retiring systems was gathered from the logistics analysis of the GSE 91-D design study, the thermoplastic manufacturers, and

Office of Environmental Management/Environmental Compliance at Nellis AFB, NV. This office is responsible for environmental management of the aircraft test range, where ordinance such as the AIM-9 is fired and is responsible for the on-going Coronet Clean operations, recovering and disposing of spent ordinance waste products from the range.

All of these data sources were asked the following questions:

1. Given the production level of 1,500 missiles and maintenance level of 16 missiles, what waste products do you now, or would you expect to produce?
2. What quantities of these wastes do you, or would you produce?
3. Do you/would you recycle these wastes?
4. How do you/would you dispose of these wastes?
5. What varibles affect the decision to recycle?
6. If 50% of the annual production of these wastes were accidentally spilled, in their normal use environment, what would be the approximate cost of cleaning the spill?
7. How would you characterize the recyclability of these wastes?
8. Given the many variables in your particular process, what would be the likely high and low values for the amount of each waste produced, the cost of cleaning up a spill of 50% of the waste, and the recyclability of the waste?

Responses to these questions were used to develop the model and to exercise the method of analysis upon the AIM-9 and Viper designs. A detailed example of how these responses were translated into scores for the model is included in Appendix E.

IV. Findings and Analysis

4.1 Introduction

The decision model was used to evaluate the production, operations and maintenance, and retirement of the AIM-9 and Viper air-to-air missiles. The same processes were also evaluated using the traditional environmental assessment methodology. The results of the two methods were compared to demonstrate the use of the decision model and its potential to improve the environmental assessment process. Values for production and retirement of the AIM-9 and Viper are based on per missile data. Values for missile operation and maintenance were based on normal annual operations of 15 missiles.

4.2 Production

The wastes which will be generated by the production of the Viper missile were estimated by thermoplastic manufacturers at the Air Force Advanced Composites Program Office and the Accutech Company. Wastes for the AIM-9 were reported by the manufacturer, Hercules Corporation. The wastes and their ratings are listed in Table 8 and Table 9.

Table 8: AIM-9 Production Waste Products

Waste	Score
Aluminized Propellant	500.0
Solvent (Ammonium Picrate)	499.0
TCA	305.5
Methyl Ethyl Ketone	90.9
Methylene Chloride	44.3
Waste Fixer Solution	5.3
Contaminated Rags (Paint & Solvent)	340.0
Dichloromethane	4.6
Xylene	0.7
1,1,1 Trichloroethane	214.1
Acetone	0.4
Paint (xylenol, toluol)	0.6
Aluminum	2.0
Isopropyl Alcohol	0.1
Toluene	0.1
Oil	1.5
Trichloroethylene	1.7
Total Score for AIM-9 Production	2010.7

Table 9: Viper production Waste Products

Waste	Score
Aluminized Propellant	200.0
Solvent (Ammonium Picrate)	30.0
HX-4000 Purge Waste	0.8
Hydraulic Fluid	0.1
Acetic Acid	0.1
Contaminated Rags (Solvent)	0.1
Grease	0.1
Total Score for Viper Production	231.0

Values for the individual design characteristics are presented in Appendix A.

The decision model score for the Viper was 231.0 This compares with a score of 2010.7 for the AIM-9. The driver for both missiles' ratings was the waste propellant produced during the loading of the rocket motor casing. Although both processes generate large amounts of waste propellant, the improved bonding characteristics of the Viper's HX-4000 material reduce this waste to less than half of the AIM-9's (Rusek;1993).

The other drivers of the AIM-9's higher score are due to solvents generated by the aluminum finishing process and the chemical washes and insulating layers needed to separate the metal motor casing from the propellant. Since the Viper's LCP casing bonds directly to the propellant, these wastes are eliminated in the Viper.

An environmental assessment of the conversion from AIM-9 to viper production, conducted using current methods, also reflects these improvements in air quality, due to the smaller volume of incinerated propellant and solvents used in insulating and bonding. However, the function provides an indication of the impact of the burned wastes than might be apparent in a traditional EA. It is clear, from the high scores of the waste propellant, solvent, TCA, and MEK, that these burned wastes are the primary drivers in the AIM-9's score. Reducing or eliminating their burning would significantly reduce the process's impact.

A series of 1,000 trials of the scoring functions for the production process produced the Weibully distributed probability density functions depicted in Figure 2. These PDFs support the significant difference between the likely impacts of the production of the Viper and the AIM-9. The PDFs showed no intersection of the two functions. The area under the PDF over any interval on the horizontal axis represents the probability of taking on a value in that interval. The area of the curves which overlap represent the probability of making an incorrect choice, based upon the results of the model. The highest probable score for the production of the Viper was far below the lowest score for the AIM-9. This result supports the environmental assessment conclusion that the Viper can be produced with a smaller environmental impact than the AIM-9.

The narrower range of the Viper PDF indicates the characteristics of this system's waste products have a smaller variance than those of the AIM-9. This tells the decision maker that the information known about the Viper contains less uncertainty than that of the AIM-9.

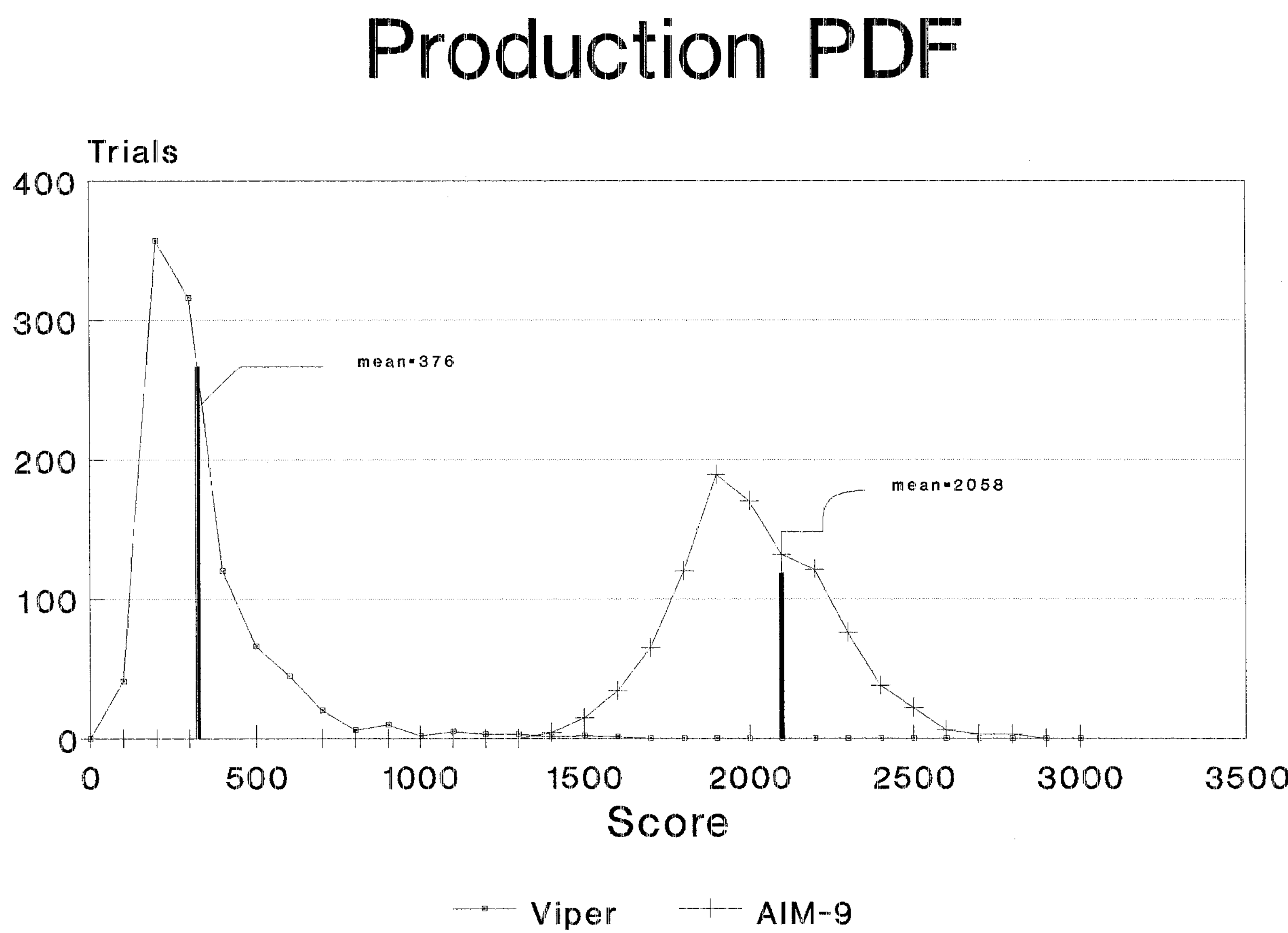

Figure 2. Production PDF

4.3 Operations and Maintenance

The wastes which will be generated by the operation and maintenance of the Viper missile and the AIM-9 were developed during extensive interviews with missile system users and maintainers assigned to the 906 Tactical Fighter Group at Wright-Patterson AFB, OH. These wastes and waste quantities are the actual amounts for annual operations and maintenance of 15 AIM-9 missiles. Wastes and quantities for the Viper were developed using the design specifications from the GSE 91-D design study to create a maintenance estimate which would meet the current missile readiness requirements. These estimates were derived by assuming a replacement supply of 15 Vipers, maintained by the 906 TFG in their existing facility. The Vipers were assumed to fly the same missions as the AIM-9s on the same aircraft. Material properties for the Viper were provided by the Air Force Advanced Composites Office and the quantities of waste were estimated by the 906 TFG maintenance supervisor, using this information. The wastes and their ratings are listed in Table 10 and Table 11.

Table 10: AIM-9 Operation and Maintenance Waste Products

Waste	Score
Solvent (Ammonium Picrate)	48.0
Aluminized Propellant	1.3
Paint (xylenol, toluol)	0.8
Aluminum	0.1
Total Score for AIM-9 O & M	50.0

Table 11: Viper Operation and Maintenance Waste Products

Waste	Score
Solvent (Ammonium Picrate)	6.0
Aluminized Propellant	0.9
HX-4000	0.1
Total Score for Viper Production	6.9

Values for the individual design characteristics are presented in Appendix A.

The decision model score for the Viper was 6.9. This compares with a score of 50.0 for the AIM-9. The difference between the missiles' scores was due to the painting and resurfacing needed by the AIM-9 which the Viper's plastic skin avoids. Both processes generate small amounts of waste propellant from damaged or defective motors and small numbers of wings and fins which are damaged during handling and cannot be repaired. A series of 1,000 trials for the operations and maintenance of both missiles was accomplished, allowing for random variation about the coefficient of variation. The PDFs produced appear in Figure 1 in section III. These PDFs depict the small range of Viper scores, due to the small number and quantities of waste products involved. The AIM-9 scores were both higher and more widely distributed. Both of these characteristics were due to the much larger volumes of solvents needed for paint stripping, and the wide variance in the amount of these solvents which may be used.

Unlike the production PDF, there is a significant area of intersection in the distributions for the two missiles in the operations and maintenance process. This overlap is, again, due to the wide range of possible values for the volume of solvents used in resurfacing the AIM-9. The overlap area represents the risk in this assessment. The narrow range of the Viper PDF indicates the low level of uncertainty in this missile's design characteristics. Since the Viper requires little maintenance, the number and amounts of wastes produced have small variances. there is not much opportunity for a wide range of waste values to be produced. The AIM-9 PDF, in contrast, is spread over a much wider range. This is because the need for resurfacing of this missile varies widely with a number of circumstances. the number and quantities of the wastes produced, therefore, have a wide variance and the model yields a wide range of possible scores.

More detailed study of the maintenance of the AIM-9 may produce more exact data and smaller variances. This would narrow the range of the AIM-9 PDF and give the decision maker better information upon which to base his or her judgment.

The environmental assessment of the conversion from AIM-9 to viper production (Appendix B) identified these improvements in air quality, due to the elimination of the resurfacing and painting of the missile. However, the normal environmental assessment does not reflect an impact for the AIM-9 more than seven times the Viper. The function scores do reflect that the impacts of operation and maintenance are significantly lower than the other two stages of the systems life cycle. However, it must be kept in mind that the production and retirement of the system are one time events, whereas the operation and maintenance of the system is a recurring, annual impact.

4.4 System Retirement

Retirement of a missile system occurs when the weapon is fired, either in combat or training, or when it is dismantled and disposed of at a depot at the end of its useful lifetime. The wastes which will be generated by the retirement of Viper missile and the AIM-9 were developed during interviews with environmental compliance managers at the Nellis AFB NV test range and Air Logistic Center managers. These wastes represent the annual retirement of 1,500 missiles. Values for the Viper were derived from the system design specifications by the test range environmental compliance managers. The wastes and their ratings are listed in Table 12 and Table 13.

Table 12: AIM-9 Retirement Waste Products

Waste	Score
Aluminized Propellant	1890.0
Aluminum	113.4
Total Score for AIM-9 O & M	2003.4

Table 13: Viper Retirement Waste Products

Waste	Score
Aluminized Propellant	1350.0
HX-4000	120.0
Total Score for Viper Production	1470.0

Values for the individual design characteristics are presented in Appendix A.

The rating for the Viper was 1470. This compares with a score of 2003.4 for the AIM-9. The LCP Viper is a lighter missile, and requires less propellant than the AIM-9 to achieve performance goals. This yields less propellant to be burned during flight, or disposed of during dismantling.

Aluminum and HX-4000 possess similar characteristics when considered for disposal. Both materials are highly persistent and easily recyclable. Aluminum requires less processing for recycling at the same level of material quality than HX-4000. Again, the primary difference between the missiles is the amount of material used and disposed of. With 63 pounds of aluminum in its frame and skin, the AIM-9 produces one-third more waste to be disposed of than does the 45 pound Viper.

A series of 1,000 trials of the decision making model, allowing the values for each characteristic to vary randomly about the coefficient of variation, produced the PDFs depicted in figure 3. These PDFs express the similarities in the environmental impacts of the retirement phases of the Viper and AIM-9 life cycles. The close mean values of the PDFs and the significant area of intersection are due to the similar properties and quantities of the wastes involved. The factors which lead to the variances in the retirement PDF are largely due to the cost of remediation which, in turn, is driven by factors not directly dependent on the material. The cost of cleaning the destroyed missile from the test range may vary widely, from instance to instance due to a range of operational and policy varibles. The PDFs tell the decision maker that there is a significant risk of making a wrong decision. The wide range of values in both PDFs indicate that better data is required to reduce this risk. However, the similar values of the PDFs indicate that the impacts of the retirement of either missile system will be similar.

The environmental assessment of the conversion from AIM-9 to viper production identified these improvements by examining the procedures used

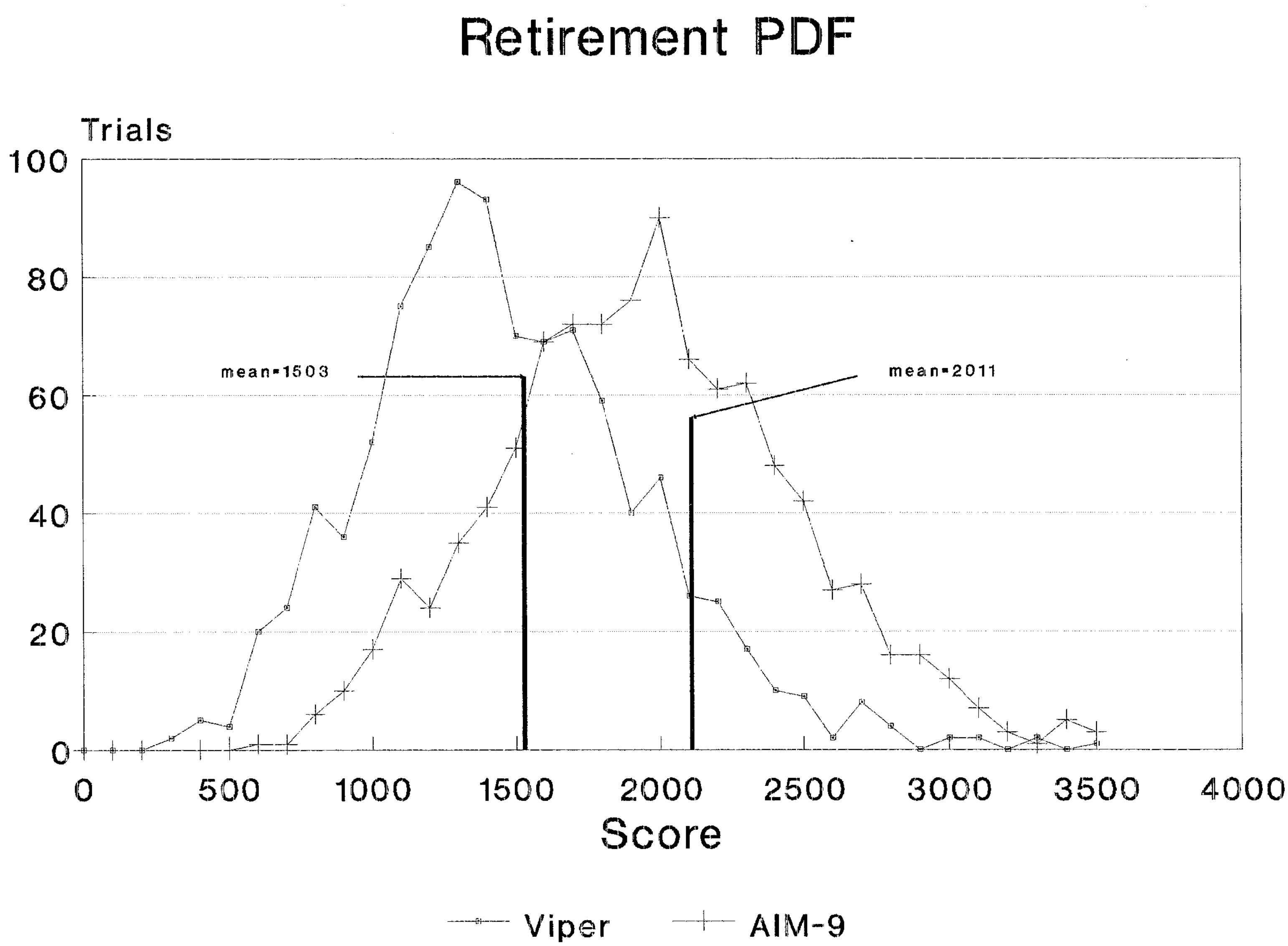

Figure 3. Retirement PDF

during Operation Cornet Clean, the annual cleanup at the Nellis Air Force Base weapons range. The EA showed the Viper causing slightly less impact than the AIM-9 because of the reduced amounts of propellant and structural material requiring disposal.

V. Conclusions

5.1 Research Summary

The National Environmental Policy Act of 1969 requires federal agencies to take into consideration the environmental consequences of a proposed action before such action is implemented. The current method of NEPA compliance is the environmental assessment, a report which considers the quantitative and qualitative impacts of a proposed action. EAs consider the toxicity and exposure risk of action products, as well as economic and social changes the action may cause. What the EA lacks is a quantitative means for assessing and comparing the impacts of dissimilar actions with different waste products.

The decision methodology proposed in this research allows for a process to be scored based upon the waste products it generates and compared against other processes when considering alternative choices.

Several steps were taken to develop this function. First, the variables which are of concern in environmental assessment of materials were developed . Then, these variables were combined into characteristics which describe the severity of the material's environmental impact. Interviews and a review of the literature were conducted to determine how these characteristics could be best evaluated and quantified, and how they interrelate with the value system used to set environmental priorities. These characteristics, and values, and the constraint relationships governing environmental impacts were then combined into a mathematical relationship which scores the environmental impact of a process generating waste materials. Statistical analysis of the relationship was conducted to indicate the level of risk due to variances in data involved in making the decision and the need for more precise data about the materials under consideration. A sample case of two alternative systems was then chosen. An environmental assessment of the systems was conducted, and the results of the methodology compared to it.

5.2 Practical Implications of the Decision Model

The immediate practical use of the method is in assisting decision makers in conducting environmental assessments of proposed actions. The function creates an objective scale for measuring the impacts of the wastes generated by a process, even if the wastes are dissimilar, of widely different volumes, and with varied characteristics.

Probabilistic methods for risk assessment are an effective and efficient use of resources. Given infinite amounts of time and money, deterministic descriptions of complicated environmental systems could be developed to great detail. However, as an alternative, the decision maker can use probabilistic and statistical methods as convenient tools to describe the state of physical phenomena.

If the mathematical relationship developed for a system is valid, probabilistic assessment procedures may avoid the inefficiency of traditional overdesign approaches and the cost of applying excessive safety margins may be avoided. By treating each nonstatistical uncertainty as a random variable, its effect upon the final model score can be quantified. The decision maker now has an indication of the degree to which more precise data is required, and can balance the cost of additional research to reduce this uncertainty with the benefits of removing the uncertainty and reducing the risk.

Although the political and qualitative aspects of each EA will have to be weighted in their own, case unique, manner, this model will allow for better comparison of actions and options, as well as for analysis of the improvements to a process which will yield the greatest improvement in the affect it has upon the environment.

Any model is an abstraction and simplification of a real problem. Ideally, it captures the essential elements and relationships from the real problem. Solving a model means obtaining logical conclusions which can be an effective guide in decision making if the model is designed and solved properly. The use of probabilistic and statistical methods to analyze the results of the model give deeper insight into the questions of risk and the need for more precise data. proper design and use of this decision methodology, integrated with judgment about qualitative factors, will yield more efficient decision making about environmental impacts.

Appendix A: Calculations for Environmental Impact Model Assessment of Production, Operations and Maintenance, and Retirement of the Viper and AIM-9 Missiles

A.1 Viper Production

Table A-1. AIM-9 Production Waste Products

Waste	Score		Waste	Score
Propellant	**500.0**		**Dichloromethanene**	**4.6**
Number Times RQ	250.0		Number Times RQ	2.3
Persistence	1		Persistence	2
Cost	2		Cost	2
Recyclability	1		Recyclability	2
Solvent	**499.0**		**Xylene**	**0.7**
Number Times RQ	249.5		Number Times RQ	0.7
Persistence	1		Persistence	2
Cost	2		Cost	1
Recyclability	1		Recyclability	2
TCA	**305.5**		**1,1,1 Trichloroethane**	**214.1**
Number Times RQ	76.4		Number Times RQ	35.7
Persistence	2		Persistence	3
Cost	2		Cost	2
Recyclability	1		Recyclability	1
Methyl Ethyl Ketone	**90.9**		**Acetone**	**0.4**
Number Times RQ	15.2		Number Times RQ	1.7
Persistence	3		Persistence	1
Cost	2		Cost	1
Recyclability	1		Recyclability	3
Methylene Chloride	**44.3**		**Paint**	**0.6**
Number Times RQ	14.8		Number Times RQ	.06
Persistence	3		Persistence	2
Cost	2		Cost	1
Recyclability	2		Recyclability	2
Waste Fixer Solution	**5.3**		**Contaminated Rags**	**340.0**
Number Times RQ	5.3		Number Times RQ	170.0
Persistence	2		Persistence	2
Cost	1		Cost	1
Recyclability	2		Recyclability	1

Table A-1 (Continued) AIM-9 Production Waste Products

Waste	Score
Trichloroethylene	**1.7**
Number Times RQ	1.7
Persistence	1
Cost	2
Recyclability	2
Oil	**1.5**
Number Times RQ	2.3
Persistence	2
Cost	1
Recyclability	3
Isopropyl Alcohol	**0.1**
Number Times RQ	0.4
Persistence	1
Cost	1
Recyclability	3
Toluene	**0.1**
Number Times RQ	0.3
Persistence	1
Cost	1
Recyclability	2
Aluminum	**2.0**
Number Times RQ	2.0
Persistence	4
Cost	1
Recyclability	4
Total Process	**2010.7**

Table A-2: Viper Production Waste Products

Waste	Score
Propellant	**200.0**
Number Times RQ	100.0
Persistence	1
Cost	2
Recyclability	1
Solvent	**30.0**
Number Times RQ	15.0
Persistence	1
Cost	2
Recyclability	1
HX-4000 LCP	**0.8**
Number Times RQ	0.4
Persistence	4
Cost	2
Recyclability	4
Acetic Acid	**0.1**
Number Times RQ	0.1
Persistence	1
Cost	1
Recyclability	1
Grease	**0.1**
Number Times RQ	0.1
Persistence	2
Cost	2
Recyclability	4
Hydraulic Fluid	**0.1**
Number Times RQ	0.1
Persistence	2
Cost	2
Recyclability	4
Contaminated Rags	**0.1**
Number Times RQ	0.1
Persistence	2
Cost	1
Recyclability	1
Total Process	**231.0**

A.2 Operations and Maintenance

Table A-3: AIM-9 Operation and Maintenance Waste Products.

Waste	Score
Propellant	**1.3**
Number Times RQ	0.6
Persistence	1
Cost	2
Recyclability	1
Solvent	**48.0**
Number Times RQ	24.0
Persistence	1
Cost	2
Recyclability	1
Aluminum	**0.1**
Number Times RQ	0.1
Persistence	4
Cost	1
Recyclability	4
Paint	**0.8**
Number Times RQ	1.5
Persistence	2
Cost	1
Recyclability	4
Total Process	**50.0**

Table A-4: Viper Operations and Maintenance Waste Products

Waste	Score
Propellant	**0.9**
Number Times RQ	0.5
Persistence	1
Cost	2
Recyclability	1
Solvent	**6.0**
Number Times RQ	3.0
Persistence	1
Cost	2
Recyclability	1
HX-4000 LCP	**0.1**
Number Times RQ	0.1
Persistence	4
Cost	1
Recyclability	3
Total Process	**6.9**

A.3 System Retirement

Table A-5: AIM-9 Retirement Waste Products

Waste	Score
Propellant	**1890.0**
Number Times RQ	945.0
Persistence	1
Cost	2
Recyclability	1
Aluminum	**113.4**
Number Times RQ	37.8
Persistence	4
Cost	3
Recyclability	4
Total Process	**2003.0**

Table A-6: Viper Retirement Waste Products

Waste	Score
Propellant	**1350.0**
Number Times RQ	675.0
Persistence	1
Cost	2
Recyclability	1
HX-4000 LCP	**120.0**
Number Times RQ	30.0
Persistence	4
Cost	2
Recyclability	3
Total Process	**6.9**

Appendix B: Environmental Assessment Of Conversion From AIM-9 to Viper Production

This EA is produced to allow for comparison between the current assessment methods and the decision model. Production of the Viper will take place at existing thermoplastic manufacturing facilities. The identity and location of these facilities will not be known until a competitive contract award process is conducted. It is expected that the eventual producer (or producers) will operate injection and extrusion manufacturing facilities similar to those currently in operation at the Air Force Advanced Composites program Office at McClellan AFB, Ca. and at Accutech Corporation in Huber Heights, Oh. These manufacturing plants have been used as the data sources for this model EA.

Summary

It is proposed that the Air Force convert from producing all metal AIM-9 air-to-air missiles to Liquid Crystalline Polymer (LCP) Viper missiles. This Environmental Assessment (EA) has been prepared to analyze the environmental consequences associated with this conversion. This assessment is prepared in compliance with the National Environmental Policy Act (NEPA) and the regulations of the President's Council on Environmental Quality (CEQ) for NEPA compliance, and Air Force regulation 19-9, which implements them. The primary impacts of the conversion would be positive. The production methods for fabricating LCP materials produces less waste than metal part production. Production facilities for the Viper will be existing plants, approved for LCP fabrication. No deterioration of in the quality of the air, land, ground water, or surface water resources would result from the conversion. Additionally, no state, local, or federal laws or requirements imposed for protection of the environment are expected to be violated, and no significant adverse impacts or cumulative effects are expected from the proposed missile conversion. The proposed conversion is not expected to be controversial, and the environmental effects are not believed to involve unknown risks.

1.0 Purpose and Need for the Proposed Action

1.1 Scope and Purpose of the Proposed Action

The desire to improve operational performance and reduce costs of aerospace systems has led researchers to investigate new materials and designs. Recent studies have proposed the use liquid crystalline polymer (LCP) plastics in airframes and rocket motors. Air Force produced designs for the Viper missile, will improve missile speed, maneuverability, and range, while significantly reducing the costs of production and maintenance (GSE;1-3). The specific purpose of converting from the AIM-9 to the Viper will be to improve the operational capabilities of air-to-air combat weapons systems, while reducing the cost of producing and operating them. The Viper will be produced by one of several existing vendors who currently produce polymer parts for other commercial uses. The types of equipment and facilities used for Viper production are the same as for other polymer products and all materials and facilities will be used in exactly the same manner. Wastes and byproducts from the process are recyclable and may be used in other production processes.

The only alternative to producing the Viper considered was the alternative of taking no action. This would mean that the Air Force would continue to use the aging, more costly, and more difficult to produce AIM-9. This alternative is in conflict with stated DOD policy, which seeks the most effective weapons systems for its combat forces.

1.2 Scope of the Environmental Law

The National Environmental Policy Act of 1969 (NEPA), the Council on Environmental Quality (CEQ) regulations implementing the Act (40 Code of Federal Regulations [CFR] 1500-1508), Department of Defense (DOD) Directive 6050.1, and Air Force Regulation (AFR) 19-2, which implements these laws and regulations, direct that DOD and U.S. Air Force (USAF) officials consider environmental consequences when authorizing or approving federal actions. Accordingly, this Environmental Assessment (EA) analyzes the potential environmental consequences of the proposed conversion from metal to polymer plastic air to air missiles.

2.0 Description of the Proposed Action and Alternatives

2.1 Description of the Proposed Action

The U.S. Air Force is proposing to convert from the AIM-9 air-to-air missile to the Viper missile. Missile production would be transferred from current manufacturers to established producers of LCP components.

2.1.1 Characteristics of Weapons System Involved

The Viper is an air-to-air missile consisting of LCP body and rocket motor. Currently used Guidance Controls, Target Acquisition Electronics, and Warhead will be incorporated into this system. The Viper will be powered by a standard aluminized grain solid rocket propellant (GSE:3-2).

2.1.2 Characteristics of the Materials Involved

Manufactured by the DuPont Chemical Corporation, HX-4000 is a thermotropic LCP. (Thermotropic LCPs exhibit crystalline Characteristics in the melted state, which differentiates them from lyotropic LCPs, which display these characteristics in solution). Thermotropic LCPs are suited for use in high stress, temperature applications because they exhibit the phenomenon of annealing, when subjected to a long duration temperature cycle, after which they will behave as a thermoset (Chew;2).

2.1.3 Plant Operations

If the proposed conversion is enacted, the facilities currently used for forming metal alloys into components for the AIM-9 missile will be replaced by those producing LCP plastic parts. The facilities used for the new part production will be factories which are already existing. These plants will operate in the same manner as they currently produce commercial polymer plastic parts.

2.1.4 Material Safety

HX-4000 and other similar LCP materials are non-toxic, non-reactive, plastics which do not conduct electricity. LCPs pose no known threats due to prolonged exposure, ingestion, or inhalation (USAF;4).

2.1.5 Process Safety

Neither of the two commercially popular methods of LCP part fabrication produces hazardous levels of noise or chemical waste. Both injection molding and extrusion molding facilities have been licensed by state and local environmental agencies and are under the jurisdiction of the Occupational Health and Safety Administration (Levy;31). Production of the Viper generates approximatley one third of the waste propellent as production of the AIM-9. The handling and incineration of this material, while not inherently dangerous when done in accordance with established saftey procedures, does pose some risk, due to the propellent's volatility (Hunt;1993).

2.1.6 Personnel Summary

The proposed action would transfer the production of 1,600 missiles a year from metal production facilities to LCP production facilities (Hunt;1993). The volume of annual part production amounts to approximately 46 weeks of full scale operation for a single injection and extrusion production facility (Frank;1993). It would be expected that approximately 25 additional workers would need to be hired to accommodate this work load (Frank;1993).

Current AIM-9 production employs approximately 150 people at various contractor locations whose jobs would be eliminated by the conversion to a polymer missile. Other workers whose efforts support AIM-9 production would be reassigned to other duties (Corley;1993).

2.1.7 Construction

The conversion to LCP missiles would require no construction. Existing manufacturing facilities have sufficient capacity to accommodate the production levels the changeover will require. Existing extrusion molding facilities may require minor modifications to improve their ability to process the large, extruded tubes required for the Viper (Frank;1993).

2.2 No Action Alternative

If the proposed conversion does not occur, the AIM-9 missile will remain the weapon system in use. The AIM-9 will be produced at its current level in existing manufacturing facilities. The No-Action alternative will mean the production of the AIM-9 will be unchanged. Excluding the environmental impacts of the mining of bauxite and its processing into aluminum, the AIM-9 production process involves "drawing" the aluminum-zinc alloy rocket motor casing. The drawing process involves pulling a pointed alloy rod through a series of successively smaller dies until it reaches the desired diameter. A steel bar called mandrel extends through the center of the die and hollows out the rod. Acid and alkaline washes are then used to give the aluminum tubing a dull finish. This wash is repeatedly recycled, but must, eventually, be neutralized and disposed of (Bowman;5).

After the motor casing is formed, it must be machined to remove excess material and insure proper shape. This machining produces approximately 250 grams of aluminum filings per missile casing. These filings are collected and recycled as much as possible, although some small portion of them are disposed of into landfills (Corley;1993).

A primary difficulty with the AIM-9 is the bonding of the rocket motor propellant to the motor casing. None of the currently used grain propellants bond with processed aluminum, nor would such bonding be desirable. Direct contact between a volatile propellant and a conductive casing would pose prohibitive safety and handling problems. To bond the propellant to the AIM-9 motor casing requires several layers of bonded insulating materials and applications of N-100 isocyanate (Chew;6).

2.3 Alternatives Eliminated From detailed Study

Alternatives to the proposed action would be to modify the AIM-9 using polymer motor and fin components. Several potential combinations of metal and polymer components were proposed, but none of these hybrid missiles achieved the cost savings or performance gains of the all-polymer Viper. Additionally, the hybrid missiles would require the same production equipment and work force as producing both the all-metal and all-polymer missiles (GSE;4-46).

3.0 Affected Environment

3.1 Physical and Demographic Setting

All areas effected by the change from metal to polymer plastics in air-to-air missile production will be existing manufacturing facilities. The actual location of the polymer component production will not be known until a producer is selected through a competitive contract award process. The pool of potential manufacturers is assumed to have existing facilities, currently in use for commercial production of polymer plastic products. These facilities will have met or exceeded state and federal environmental standards for manufacturing facilities. Environmental Assessments for these manufacturing facilities will address the affects they have on the surrounding environment.

For the purpose of this study, three existing manufacturing facilities have been used to model the affected environment. The Air Force Advanced Composites Laboratory was used to model the producers of extruded LCP components. The Accutech Company of Huber Heights, Ohio was used as the model for injection molded LCP manufacturers. The Hercules company was used as the model for AIM-9 production.

Noise, air, and water quality within and surrounding all three production facilities is strictly governed by federal, state, and local pollution control standards. All three plant environments conform to manufacturing zoning laws and OSHA standards for working conditions.

4.0 Environmental Consequences

This section presents the results of the analysis of the potential environmental effects of implementing the proposed conversion from producing metal to producing polymer plastic air-to-air missiles. Changes to the natural and human environments which might result from the Proposed Action were evaluated relative to the affected environment. Possible direct and indirect effects were assessed both qualitatively and quantitatively, considering both short and long term effects. The potential for significant environmental consequences was evaluated using the intensity and context considerations defined in CEQ regulations for implementing the procedural provisions of NEPA (40 CFR 1508.27).

Plastic part production offers great advantages over traditional metal production methods because several parts can be consolidated into one molded assembly (Leopold;289). There are two primary methods of polymer plastic part production, injection and extrusion molding.

Injection molding is the process of taking a raw polymer material (typically a powder, granules, or pellets) melting it and quickly forcing it into a mold under high pressure. After cooling, the molded plastic is removed from the mold, inspected, and the process is repeated. The advantage of this process is that parts and assemblies are produced cheaply and quickly in large volumes. Molded polymers typically require very short periods (less than one minute) to solidify after injection and the resulting part usually requires little or no additional work prior to use (Leopold;288). Complex parts that would otherwise require welding or gluing can be produced in one step during the molding process. Recent technological advances in machine control enable the mass production of low variability, high quality parts and provide promise for much future use in the aerospace industry.

Production of either the AIM-9, or Viper missiles would take place at existing production facilities. These facilities will be in compliance with all applicable state, local, and federal statutes and regulations. Manufacturing facilities are governed by Occupational Safety and Health Administration (OSHA) regulations.

Cumulative impacts result from "the incremental impact of the action when added to other past, present, and future actions regardless of what agency undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time" (CRS;13). If the production facility is used exclusively for activities similar to the Viper production, the Proposed Action should not contribute to any long term impacts.

Potential impacts to the natural and human environments resulting from the implementation of the Proposed Action would be minor. Potential impacts to the natural and human environments considered in this assessment related to air quality, water quality, noise, land use, hazardous materials/waste management, health and safety, cultural resources, infrastructure, and socioeconomic. A brief summary of these resources follows.

4.1 Air Quality - Implementation of the Proposed Action would result in lower emissions of air pollutants than from the current AIM-9 production. During the extrusion production process, approximately 3 grams of acetic acid per missile will be produced. This by-product is captured and recycled without exposure to workers. The Air Force Advanced Composites Program Office extrusion manufacturing facility at McClellan AFB, Ca produces polymer plastic components on the necessary scale and has been cleared by the Sacramento, California Air Pollution Control District (CAPCD;1990). Viper rocket motors will be extruded as 1.8 meter sections. These sections will be "sawed off" from the continuously flowing "tube" of LCP and propellant. This separation process will yield approximately 150 grams of polymer "saw dust" which is recaptured through a vacuum system attached to the saw. Although the polymer is considered completely inert and harmless when inhaled, workers involved in this procedure, or in the immediate area of it, wear protective filtering masks to avoid inhalation of the dust (Frank;1993). Accumulated polymer dust is easily recycled, as it is already close to a powdered form.

Viper production also produces significantly lower volumes of burned wastes, due to the elimination of propellent insulation and bonding processes (Frank;1993).

4.2 Water Quality - The production of polymer plastic components yields no hazardous by-products which might affect the water supply. Since the small amounts of acetic acid produced occur in the melt stage, they exist in a contained environment and have no opportunity for entering the water supply. Even in the event of an accidental release, these by-products would be contained by the rapidly cooling LCP and little threat of contamination (Frank;1993). AIM-9 production produces several potentially harmful solvents and manufacturing by products, all of which are disposed of according to federal, state, and local regulations (Bowman;6). Significant impacts to water resources would not be expected from the proposed action.

4.3 Noise - Noise levels for both the Viper and AIM-9 will remain the same as they are under current production conditions, if the Proposed Action or No-Action alternative are adopted, respectively. Occupational Health and Safety Administration (OSHA) regulations will apply to all involved production facilities. No significant impacts to the noise environment would be expected.

4.4 Land Use - Production of LCP Vipers would require no additional land use, compared to current missile production. Land surrounding the production facility would be unaffected by the Proposed Action. Both the Proposed Action and the No-Action alternative would use existing production facilities without additional land use.

4.5 Hazardous Materials/Waste Management - No significant impacts would occur in this area due to the Proposed Action. The types and volumes of hazardous materials/waste expected from the proposed action would be similar to those associated with current polymer molding operations. Extrusion molding produces small amounts of volatile substances, which are collected and recycled. No releases of hazardous materials occur in this process (Frank;1993). These operations have been approved by responsible state and local agencies (CAPCD;1990).

Extrusion processing also produces "purge" waste. This is polymer which is run through the system at the start of production to "prime" the machinery and achieve sufficient material flow for the parts to be produced. Purge waste is also produced at the end of a production session. When the system is shut down, material remaining in the system hardens and must be removed.

As with all polymer waste, the purge waste is not desirable for disposal in landfill. LCP materials, without protective coatings, will break down to an inert, fine-grained powder under prolonged exposure to ultraviolet light. Complete degradation of a one inch thick section of LCP, left exposed to ultra-violet radiation, is expected to take 100 years. When buried, the LCP remains intact indefinitely. Buried in a landfill, LCP is forever (Frank;1993).

Recycling the LCP is an attractive alternative to disposal. LCP materials may be ground back into a powder or melted for reuse. Although recycled LCP is currently unsuited for use in high-stress, high flow consistency applications such as the Viper, it is well suited to reuse in lower grade plastic applications. Recyclability into such uses as plastic containers appears to be unlimited. That is to say, the plastic may be repeatedly recycled for use at this level of material integrity (Frank;1993). Current research is close to fielding a commercial process which will allow the recycling of LCP materials back to their original form, with no loss of material characteristics. This process will allow the reuse of viper production waste material, although it may be economically more efficient to reprocess the waste into lower grade plastics (Frank;1993).

Adoption of the No-Action alternative will lead to no changes in the current process of AIM-9 production.

4.6 Health and Safety - HX-4000 is an inert plastic which poses no threat if inhaled as a powder, or placed in contact with body tissue (Du Pont:3). The control of any potential impacts would be based on established procedures and equipment specified by OSHA regulations. The current AIM-9 production process involves several powerful metal forming and stamping machines which require strict operator safety precautions, automatic shut-off devices, and operator eye protection. Polymer plastic manufacturing facilities are already subject to OSHA regulations. Neither injection, nor extrusion molding of parts is significantly more hazardous than other production methods. The No-Action alternative would make no changes to existing facilities, materials, and procedures, and would produce no additional health and safety hazards. Overall, no health and safety impacts would be expected.

4.7 Biological Resources - Implementation of the Proposed Action would result in no change in available habitat to biological species around the production facility. Production of the polymer Viper will require no additional land or water use over and above current production of other products. Federally or state threatened or endangered species will face no increase in threats due to the use of HX-4000. Under the No-Action alternative, production of the AIM-9 will continue in existing facilities already approved for use.

4.8 Cultural Resources - The production of the polymer Viper would take place at existing manufacturing facilities. The use of HX-4000 will have no effect upon known historic or cultural resources. All production facilities will be used in the same manner as they are presently used, with little or no expansion required. The additional volume of production would not significantly affect the size or nature of plant operations. No impacts to cultural resources would occur.

No additional disturbance to cultural resources would result from the No-Action alternative.

4.9 Infrastructure - Current infrastructure is adequate to handle the Proposed Action. No additional roads or facilities will be required at or near the production facilities due to the change in material or production levels. The current infrastructure is also adequate to accommodate the No-Action alternative. Production facilities for the AIM-9 function with the current infrastructure. No changes to these facilities are proposed (Corley;1993).

4.10 Socioeconomic - The conversion from metal to polymer plastic missile production should cause no significant socioeconomic impact, since the current producers of the AIM-9 will also be actively pursuing the final assembly and propellent loading tasks for the Viper. Some AIM-9 parts suppliers may experience a decrease in personnel employed, although the amount of conversion from metal to polymer missiles would increase employment at the polymer manufacturing facility by 25 people, if the production were conducted at a single facility. Halting AIM-9 production will lead to an aggregate loss of 45 jobs at 3 separate facilities (Corley;1993).

Appendix C: Environmental Assessment of Conversion From AIM-9 to Viper Operations and Maintenance

Once produced, the Viper will be transported, in pieces, to its operating units. The 906 Tactical Fighter Group at Wright-Patterson AFB, OH was used as the model for such a unit. The 906 TFG currently maintains 16 AIM-9 missiles for use in air combat training missions. If the conversion to the Viper were to take place, the 906 TFG would replace its inventory of AIM-9s with an equal number of Vipers. These missiles would then be assembled, flown, and maintained at the 906 TFG maintenance facilities, Building 4064, at Wright-Patterson AFB.

Summary

This Environmental Assessment (EA) has been prepared to analyze the environmental consequences associated with the Operation and Maintenance of Viper air-to-air missiles. This assessment is prepared in compliance with the National Environmental Policy Act (NEPA) and the regulations of the President's Council on Environmental Quality (CEQ) for NEPA compliance. Section 1 presents the purpose and need for the action. Section 2 describes the project in detail, including alternatives, and summarizes impacts of the action. Section 3 describes the physical and human environments affected by the proposed action. Section 4 describes the potential impacts of implementing the proposed action and alternatives and any mitigation measures required as part of the proposed action.

The fielding of Viper air-to-air missiles as the replacement for the current AIM-9 will will improve missile speed, maneuverability, and range, while significantly reducing the costs producing and operating them. The Viper will operate in the same operational and maintenance environments as the AIM-9. It has been specifically designed to use existing support equipment and facilities and to use them in the same manner as they currently operate.

The only alternative to deploying the Viper considered was the alternative of taking no action. This would mean that the Air Force would continue to use the aging, more costly, and more difficult to produce AIM-9. This alternative is in conflict with stated DOD policy, which seeks the most effective weapons systems for its combat forces.

Potential impacts to the natural and human environments resulting from the implementation of the Proposed Action would be minor. Potential impacts to the natural and human environments considered in this assessment related to air quality, water quality, noise, land use, hazardous materials/waste management, health and safety, cultural resources, infrastructure, and socioeconomics. A brief summary of these resources follows.

Air Quality - Implementation of the Proposed Action would result in minor improvements in the air quality in the vicinity of the maintenance facility.

Water Quality - If the Proposed Action were implemented, there would be no effect upon water resources compared to what they are with the current AIM-9.

Noise - Noise levels in the maintenance facility for the Viper would be comparable to those using the AIM-9. Occupational Health and Safety Administration

(OSHA) regulations will apply to the production facility. No significant impacts to the noise environment would be expected.

Land Use - Operations and Maintenance of Viper missiles would require no additional land use, compared to current missile operations. Land surrounding the maintenance facility will be unaffected by the Proposed Action.

Hazardous Materials/Waste Management - The Viper Missile will require no painting or resurfacing. This will eliminate the need for the paints, solvents, and sanding currently used to keep the AIM-9 in working condition. The polymer materials used in the Viper will require no resurfacing or hazardous materials. No significant impacts would occur in this area due to the Proposed Action.

Health and Safety - Missile maintenance facilities which will be used for the Viper are already subject to OSHA regulations. Prolonged exposure to HX-4000 produces no known health risks to humans, animals, or plant life. HX-4000 is an inert, non-flamable, plastic. The Viper will be used in the same manner as the AIM-9 and will follow the same safety regulations. Overall, no health and safety impacts would be expected.

Cultural Resources - The deployment of the Viper for normal use in the 906 Tactical Fighter Group would take place at existing maintanence facilities. The change from AIM-9s to Vipers wll not significantly affect the size or nature of facility operations. All Viper ground operations will be conducted on restricted government facilities. No impacts to cultural resources would occur.

Infrastructure - Current infrastructure is adequate to accommodate the change from the AIM-9 to the Viper. The Viper will use the same facilities as the AIM-9 and will use them in the same manner (GSE;5-60). The Viper will, however, eliminate the need for the use of paint stands which control the spread of airborne pollutants.

Socioeconomics - The conversion from metal to polymer plastic missiles should cause no significant socioeconomic impact. There is some possibility of injection molding manufacturers in the Wright-Patterson AFB, OH area may become suppliers for some replacement parts. The potential for replacement parts is estimated at 12 per year (GSE;4-56). No other impacts are anticipated due to this change.

1.0 Purpose and Need for the Proposed Action

The National Environmental Policy Act (NEPA), the Council on Environmental Quality (CEQ) regulations implementing the Act (40 Code of Federal Regulations (CFR, 1500-1508), Department of Defense (DOD) Directive 6050.1, and Air Force Regulation (AFR) 19-2, which implements these laws and regulations, direct that DOD and U.S. Air Force (USAF) officials consider environmental consequences when authorizing or approving federal actions. Accordingly, this Environmental Assessment (EA) analyzes the potential environmental consequences of the proposed conversion from the AIM-9 air to air missiles to the Viper air to air missile.

The USAF continues to improve its air to air combat forces through the introduction of new technologies and materials. The use of Liquid Crystalline Polymers (LCP) in the air frames and rocket motor casings has produced significant improvements in missile air speed, maneuverability, and range. Additionally, the LCP missiles cost half of what current AIM-9 missiles cost to produce and will require significantly fewer people and procedures in maintenance and handling (GSE;3-59).

The objective of the Proposed Action is to improve the performance of the 906 Tactical Fighter Group's air to air combat weapons systems by deploying Viper missiles constructed of LCP materials to replace all metal AIM-9 missiles. The Proposed Action addressed in this assessment is the operations and maintenance of Viper missiles.

1.2 Scope of the Environmental Law

This EA describes and addresses the potential environmental impacts of operating and maintaining Viper air to air missiles. The EA also presents mitigation measures to reduce or eliminate environmental impacts. These measures would be incorporated into operations and maintenance procedures. The EA also evaluates potential alternatives to the Proposed Action, keeping in mind their impact on the project's objectives and mission requirements.

In accordance with AFR 19-2 and the CEQ regulations, the scope of analysis presented in this assessment is defined by the potential range of environmental impacts that would result from implementation of the Proposed Action. Evaluation indicated no adverse long or short term impacts to physical resources.

2.0 Description of the Proposed Action and Alternatives

2.1 Description of the Proposed Action

The USAF is proposing to convert from deploying AIM-9 air to air missiles, constructed of metal alloys, to Viper missiles made from LCP plastic materials at the 906 Tactical Fighter Group located at Wright-Patterson Air Force Base Ohio.

2.1.1 Characteristics of the Materials Involved

Manufactured by the DuPont Chemical Corporation, HX-4000 is a thermotropic LCP. (Thermotropic LCPs exhibit crystalline characteristics in the melted state, which differentiates them from lyotropes, which display this characteristics in solution). Thermotropic LCPs are suited for use in high-stress, high temperature applications because they exhibit the phenomenon of annealing, when subjected to a long duration temperature cycle, after which they will behave as a thermoset (Chew:2).

2.1.2 Maintenance Operations

If the proposed conversion is enacted, the facilities currently used for preparing AIM-9 missiles for use on F-16 aircraft, joining the missiles to the aircraft, transporting, and repairing the AIM-9s would be used for the Viper missiles. These facilities will operate in the same manner as they are currently used for the AIM-9 (GSE:4-59).

2.1.3 Material Safety

HX-4000 and other similar LCP materials are non-toxic, non-reactive, plastics which do not conduct electricity. There are no known health affects due to exposure (Du Pont:4).

2.1.4 Process Safety

The Viper missile will be maintained and transported in the same manner as the AIM-9. The Viper has been specifically designed to use AIM-9 support equipment and to require only minimal modifications to the F-16 weapons stations. The Viper will follow the existing AIM-9 maintenance process, and all AIM-9 safety procedures will remain in effect (GSE;4-59).

2.1.5 Personnel Summary

The proposed action would reduce the amount of assembly time required for each missile and eliminate the need for painting and resurfacing. The current day-to-day, peacetime manning of the 906 Tactical Fighter Group Munitions Maintenance shop is three people dedicated to performing maintenance tasks (Sturm;1993). The shop operates sixteen hours a day, five days a week. The conversion from AIM-9 to Viper missiles will yield a net savings of 43 hours per missile annually (GSE;4-56). Modification of duty schedules may allow for small reductions in manning, although there are several procedures which require all three maintenance people and overall manning must remain close to current levels in order to accommodate surge operations (Sturm;1993). No immediate change in the number of maintenance personnel is expected, due to the proposed action.

2.1.6 Construction

The conversion to LCP missiles would require no construction. Existing maintenance facilities have sufficient capacity to accommodate the Vipers. Implementation of the proposed action should result in a reduction of maintenance procedures and the time required for them, which will produce increased capacity in the existing facility (Sturm;1993).

2.2 No Action Alternative

If the proposed conversion does not occur, the AIM-9 missile will remain the weapon system in use. The AIM-9 will be maintained at its current level in existing maintenance facilities.

2.3 Alternatives Eliminated From Detailed Study

Alternatives to the proposed action would be to modify the AIM-9 using polymer motor and fin components. Several potential combinations of metal and polymer components were proposed, but none of these hybrid missiles achieved the cost savings or performance gains of the all-polymer Viper. Additionally, the hybrid missiles would require higher maintanence hours and more procedures than either the all-metal or all-polymer missiles (GSE;4-56).

3.0 Affected Environment

3.1.1 Wright-Patterson AFB

Wright-Patterson AFB occupies 8,174 acres and contains 1,652 buildings and 2,345 housing units. The base employs more than 33,000 military and civilian personnel and is a major social and economic force in the area.

About 100 tenant organizations are located on the base. The host organization for the base is the 2750th Air Base Wing. The wing is responsible for the operation and maintenance of the facility and employs about 16% of the base staff. Administratively, Wright-Patterson AFB is subdivided into three areas: A, B, and C. Area A contains the headquarters building for the Air Force Materiel Command (AFMC), the USAF Medical Center, military family housing, and other military facilities. Area C, which is contiguous to area A, houses the headquarters for the 2750th Air Base Wing, the 4950th Test Wing, Airmen's Quarters, and several other military facilities. Also located in area C is the primary runway for the base, which is 300 feet wide by 12,600 feet long. Area B is south of Areas A and C and is physically separated from the rest of the base by State Route 444. The principal tenants of area B include the Aeronautical Systems Center, Air Force Aerospace Medical Research Laboratory, Air Force Institute of Technology, and the Air Force Museum (USAF 1987:10).

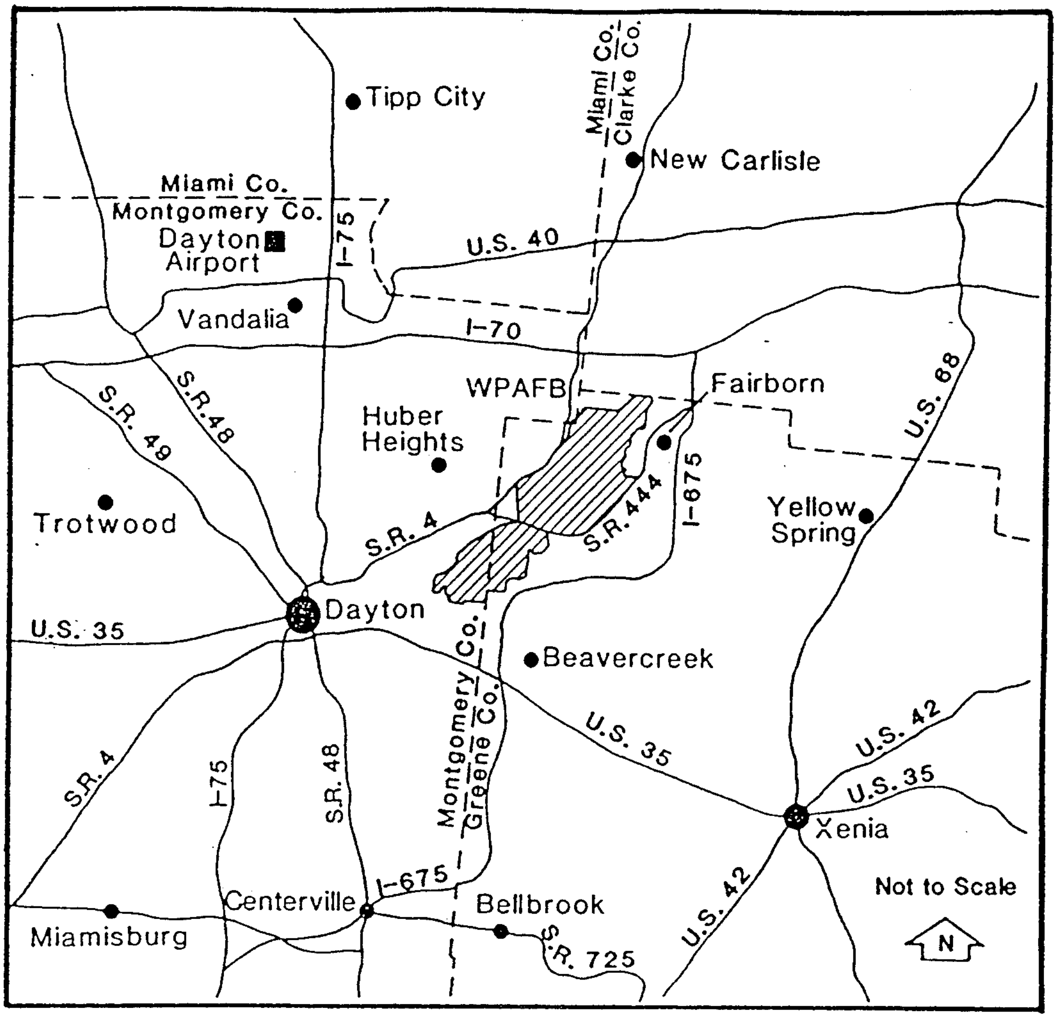

Figure C-1. WPAFB

3.1.2 Dayton and Surrounding Region

Wright-Patterson AFB is located in portions of both Greene and Montgomery Counties in southwestern Ohio. It is adjacent to Dayton (population 196,454), 64 miles northeast of Cincinnati, and 70 miles southwest of Columbus. Other nearby cities include Fairborn (population 28,652), located directly east of the base; Huber Heights (population 42,588), northwest of the base; and Beavercreek (population 33,435), located directly south of the base. Wright State University is southeast of the base (Woolpert;34).

3.2 Environmental Setting

3.2.1 Air Quality

Wright-Patterson AFB is located in the Montgomery County Air Quality Control Region (AQCR 173). That region includes the city of Dayton, where there are a total of 40 instruments measuring air quality. These instruments are at a government and industry operated sites required by the Ohio EPA and include 21 samplers for total suspended particulates (TSP), 2 for particulate matter with a diameter of less than 10 micrometers (PM-10), 2 for lead, 3 for sulfate, 3 for sulfur dioxide, 1 for nitrogen oxides, 2 for carbon dioxide, 5 for ozone, and one for wind speed and direction. Recent measurements have shown possible violations of environmental standards for ozone, however other criteria pollutants show no violations for ambient air quality standards (USAF 1987;12).

3.2.2 Wastes

Nonhazardous Waste

A sanitary sewerage system connects several developed areas of the Wright-Patterson AFB to two wastewater treatment plants: the Dayton Wastewater Treatment Plant (WWTP) and the Fairborn Sewage Treatment Plant. The latter receives waste from northeast portion of Area C, consisting of domestic wastes and wastewater from aircraft maintenance facilities. The Fairborn plant is designed for a flow of 5.5 million gallons per day and currently operates at about 70% of capacity, treating 3.8 million gallons per day. Contributions from Wright-Patterson to this operating flow are minimal. Effluent from the second (activated sludge) treatment plant is discharged into the Mad River (USAF 1987;21). Most of the non-hazardous waste generated at Wright-Patterson AFB is treated at the Dayton WWTP. The Dayton plant is designed for a flow of 72 million gallons per day, and the current average treatment rate is 57 million gallons per day. Effluent is discharged into the Great Miami River.

The two treatment plants receive approximately 4.6 million gallons per day of waste from Wright-Patterson AFB. In addition to sanitary sewage, the waste volume includes non-hazardous solutions of neutralized acid/base electroplating wastes and chemical oxidants, wash rack soap and detergents, storm water, and wastes from photo finishing and metal-cleaning operations (USAF 1987;21).

Fly ash from two coal-fired central heating plants is disposed of on site at landfill 5 (in the southwestern portion of Area A), the only active landfill on the base. This landfill receives only the ash and demolition debris. There is no on-site disposal of sanitary or hazardous solid wastes. Empty gas cylinders and bottles are returned or recycled whenever possible. All other solid refuse is collected from dumpsters located throughout the base and hauled to the county landfill by a private contractor (USAF 1987;12).

Hazardous Wastes

Hazardous wastes generated at the base are managed in accordance with federal, state, and USAF regulations. The bulk of this material is packed in containers for pickup and off-site disposal in approved landfills. Approximately 60 tons of hazardous waste are transported off-site. This waste includes laboratory waste chemicals, cleaning solvents, used lubricating oils, electroplating and paint-stripping wastes, and batteries (USAF 1987;22).

Low-level radioactive waste is generated in laboratories and the Medical Center. It is managed by the radiation protection officer of the Bioenvironmental Engineering Directorate in accordance with 10 CFR Part 20 and USAF regulations. Major isotopes include cobalt-60, cesium-137, and tritium (USAF 1987;23).

The base hazardous waste management plan contains provisions for personnel training, spill prevention and control procedures, contingency actions, and review and update procedures. This overall plan includes a spill prevention and response plan.

The combined volume of various fuel tanks on the base exceeds 7 million gallons, with JP-4 jet fuel accounting for nearly 80% of the total (USAF 1987;22). There are additional on-site storage tanks for solvent and deicing fluids. Asphalt-covered dikes in the petroleum, oils, and lubricants storage areas serve as lateral containment for spills.

3.2.3 Water Resources

Wright-Patterson AFB is adjacent to the Mad River and is drained by the river and its tributaries. Huffman Dam is located on the Mad River immediately downstream of the base. The dam is a flood-retarding structure with a dry basin, except during major floods. A majority of areas A and C of the base are located within the retarding basin (USAF 1987;24).

Surface Water Quality

The base operates with an NPDES permit that places limits on water quality parameters for discharges through the base storm drains. Limits are placed on suspended solids, pH, oil/grease, iron, chromium, and copper. Historically, the discharge limit on suspended solids has been exceeded an average of 13 times per year for the five active discharge points combined (USAF 1987;12).

Ground Water Quality

Several studies cited in a report prepared for the Wright-Patterson Installation Restoration Program indicate that the regional aquifer is susceptible to pollution as a result of waste disposal (USAF 1987;27).

3.2.4 Vegetation and Wildlife Resources

Undeveloped areas on the Wright-Patterson AFB include wetlands and lakes, woodlands, and grasslands. Wetlands and lakes provide 67 acres of habitat for waterfowl and fish (USAF 1987;28). These areas support floating and emergent plant species. Wetlands play an important role in local surface drainage, groundwater recharge, and pollutant transformation.

495 acres of the base is woodlands. These woodlands are inhabited by a number of vertebrate species, including squirrels, white-tailed deer, woodchucks, rabbits, and red fox.

The Huffman prairie is a 109 acre protected grassland in Area C. This preserve contains at least 23 indicator plant species (USAF 1987;28).

3.2.5 Threatened and Endangered Species

No federally designated endangered or threatened animal or plant species have been observed at the base (USAF 1987;29). The Ohio Department of Natural Resources does list three rare species found here: one plant - the glade mallow, one bird - the upland sandpiper, and one snake - the eastern massasauga rattlesnake. No critical habitats have been found on the base.

3.2.6 Socioeconomics

The population of the region near Wright-Patterson AFB has been decreasing during the past two decades. However, Greene County, in which most of the base is located, has experienced a relatively stable population. This regional population decline has made Wright Patterson increasingly important to the local economy. The base contributes more than $759 million per year to the local economy. Wright-Patterson currently employs approximately 16,000 government civilians, 9,000 military, and 5,000 service and contract employees. It is the largest employer among all USAF bases worldwide (Woolpert;14).

3.2.7 Cultural Resources

Wright-Patterson is one of the oldest USAF bases in active service. Several sites on the base are listed in the National Register of Historic Places, including the Wright Hangar/Huffman Prairie, a prehistoric Adena mound, and the Wright Brothers Memorial Hill. The area is also rich with archeological sites, although no systematic archeological survey of the base has been conducted (Woolpert;15).

4.0 Environmental Consequences

This section presents the results of the analysis of the potential environmental effects of implementing the proposed conversion from metal to polymer plastic air-to-air missiles. Changes to the natural and human environments which might result from the Proposed Action were evaluated relative to the affected environment. Possible direct and indirect effects were assessed both qualitatively and quantitatively, considering both short and long term effects. The potential for significant environmental consequences was evaluated using the intensity and context considerations defined in CEQ regulations for implementing the procedural provisions of NEPA (USAF 1986;1508.27).

Cumulative impacts result from "the incremental impact of the action when added to other past, present, and future actions regardless of what agency undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time" (CRS;7). If the maintenance facility is used exclusively for activities similar to the Viper maintenance, the Proposed Action should not contribute to any long term impacts.

4.1 Direct and Indirect Effects and Their Significance

4.1.1 Air Quality

By eliminating the painting and resurfacing procedures, the conversion from the AIM-9 to the Viper should yield improvements in the air quality of the area surrounding the maintenance facility. During the AIM-9 resurfacing and painting process, approximately .5 gallons of solvents and a quart of aerosol paint are used. This resurfacing is conducted in a closed facility to minimize atmospheric emissions (Sturm;1993). The painting of the AIM-9 involves the use of polyurethane and lead paints. Although maintenance personnel used gloves, face-masks, and respirators during the painting process, these measures are not considered effective due to the poor warning properties of the isocyanates involved. Even if the no action alternative is chosen, actions to correct this situation will need to be taken (Kathan;2). No other procedures involving the Viper should effect the air quality differently from effects currently experienced in the use of the AIM-9.

4.1.2 Wastes

Hazardous Materials/Waste Management - No hazardous materials/waste are expected to be produced from the proposed action. Transportation, storage, assembly, and repair of the Viper will neither require, nor produce any such materials (Rusek;1992). Elimination of the resurfacing and painting operations will reduce the volume of solvents by 130 gallons per year. This amount will have a relatively small effect on the overall volume of hazardous wastes produced by the base and will not change procedures for the handling and disposal of such wastes as a consequence of the proposed conversion.

Non-Hazardous Waste

The number of assigned workers in the maintenance squadron will not significantly change due to the proposed action. The volume and composition of postconversion sanitary effluents are expected to be unchanged from existing flows.

The volumes of liquid nonhazardous waste generated by research laboratories and routine base operations would be unaffected by the proposed conversion.

4.1.3 Water Resources

Both the Proposed Action and the No-Action alternative will make no changes to current water resources. Current maintenance facilities meet all local, state, and federal water protection standards (Kathan;2).

Although the maintenance facilities are located in the hundred year flood plane of the Mad River (USAF 1987;50), the proposed action should have no effect on the potential impacts of a flood on the river. Maintenance operations in the facility will be unchanged by the conversion and no additional hazardous materials will be used. The overall effect of the conversion on the water resources of the base and its surrounding area will be negligible.

4.1.4 Noise - Noise levels for both the polymer Viper and AIM-9 will remain the same as they are under current maintenance conditions, if the Proposed Action or No-Action alternative are adopted, respectively. Current maintenance facilities have a cumulative noise exposure level of 78.6 dBA over 8 hours. This level is below the AFR 161-35 standard of 85 dBA over 8 hours. Personnel are, however, periodically exposed to high levels of noise and should be monitored under the Hearing Conservation Program (Kathan;1).

4.1.5 Health and Safety - Currently, shop personnel use air purifying respirators while performing painting and resurfacing operations. These respirators are considered inadequate for this type of operation due to the poor warning properties of isocyanates and the current resurfacing procedures are not in compliance with AFOSH Respiratory Protection Standard 161-1 (Kathan;2). HX-4000 is an inert plastic which poses no threat if inhaled or placed in contact with body tissue (Frank;1993). The use of HX-4000 would eliminate the need for missile resurfacing.

4.1.6 Land Use - Both the Proposed Action and the No-Action alternative would use existing maintenance facilities without additional land use (GSE;4-59).

4.1.7 Infrastructure - Current infrastructure is adequate to handle the Proposed Action. No additional roads or facilities will be required (GSE;4-60). Use of the Viper would eliminate the need for a paint stand. The current infrastructure is also adequate to accommodate the No-Action alternative.

4.1.8 Vegetation and Wildlife Resources

No breeding bird species or habitats critical to sensitive species are expected to be significantly affected by the proposed conversion. Protection of a group of selected plant and animal species and enhancement of their habitats are being actively pursued under a natural resources management program on the base. The program would not be affected by implementation of the proposed conversion.

Implementation of the Proposed Action would result in no change in available habitat to biological species around the maintenance facility. Operation and maintenance of the Viper will require no additional land or water use over and above AIM-9 O & M. Federally or state threatened or endangered species will face no increase in threats due to the use of the Viper. Under the No-Action alternative, use of the AIM-9 will continue in existing facilities already approved for its use.

4.1.9 Threatened and Endangered Species

Neither federally designated endangered or threatened species, nor habitats critical to such species have been reported to exist on the base. Thus, no species or critical habitats would be affected by the proposed conversion.

The glade-mallow is listed as a potentially threatened plant species by the State of Ohio. It is reported to occur in the vicinity of Huffman Prairie in Area C, but not in the area of the maintenance facility. These facilities are routinely mowed and subject to other occasional disturbances. Therefore, it is unlikely that future populations of the glade-mallow would jeopardized by the proposed action (USAF 1987;24).

Open grassland is the typical habitat of the upland sandpiper, a state-designated endangered bird species that breeds in several locations on the base, including portions of Area C. However, the species has not been observed at any of the maintenance facilities, which are essentially urbanized areas. It is unlikely that future populations of this species would be significantly affected by the proposed missile conversion (USAF 1987;53).

The eastern massasauga rattlesnake is unofficially identified as a potentially threatened animal species by the Ohio Division of Natural Areas and Preserves. The species has been observed near Hebble Creek in Area C, not in the vicinity of the maintenance facility. The conversion from the AIM-9 to the Viper would not likely impact populations of this rattlesnake (USAF 1987;53).

4.1.10 Socioeconomics

No significant adverse social or economic effects would be associated with the proposed conversion. The conversion would result in only minor changes in the number of operational and maintenance personnel and thus would not influence local trends in population growth and distribution. The conversion might produce some small economic benefits to injection molding manufacturers in the area, who might produce some replacement parts for the Viper. However, the number of replacement parts which might be needed would not be large enough to require the hiring of additional workers (George;1993).

4.1.11 Cultural Resources

The proposed conversion would have no affect beyond the confines of the maintenance facilities and should have no adverse impact on significant historic properties. No activities involved in the conversion should have any impact upon archeological remains. All maintenance facilities will be used in the same manner as they are presently used, with no expansion required. No additional disturbance to cultural resources would result from the No-Action alternative.

4.2 Relationship of Proposed Action to Objectives of Land Use Plans, Policies, and Controls

The proposed missile conversion is not expected to adversely affect the overall objectives of current land use plans, policies, and controls of areas adjacent to Wright-Patterson AFB.

Appendix D: Environmental Assessment of Conversion From AIM-9 to Viper Retirement

As with all things, a weapons system eventually reaches the limit of its usefulness and must be disposed of. The propellant used in the Viper is sensitive to repeated handling and has a long (but not unlimited) shelf life (Chew;8). Eventually, all missiles are either fired, or dismantled and disposed of. This section of the investigation will examine the retirement of the Viper, ignoring those aspects related to propellent disposal. Removal and destruction of the propellant will be the same in both the Viper and AIM-9 and is unaffected by the material it has been removed from.

Recovery and recycling information is based upon the results of the 1992 Coronet Clean operation at Nellis AFB, NV. This involved the systematic recovery of spent ordinance on the base's primary weapons range.

Summary

This Environmental Assessment (EA) has been prepared to analyze the environmental consequences associated with the retirement of Viper air-to-air missiles. This assessment is prepared in compliance with the National Environmental Policy Act (NEPA) and the regulations of the President's Council on Environmental Quality (CEQ) for NEPA compliance. Section 1 presents the purpose and need for the action. Section 2 describes the project in detail, including alternatives, and summarizes impacts of the action. Section 3 describes the potential affects of the action on the physical and human environments. Section 4 describes the potential impacts of implementing the proposed action and alternatives and any mitigation measures required as part of the proposed action.

The fielding of Viper air-to-air missiles as the replacement for the current AIM-9 will improve missile speed, maneuverability, and range, while significantly reducing the costs of maintenance, while reducing the cost of producing and operating them. The Viper will operate in the same operational and maintenance environments as the AIM-9. It has been specifically designed to use existing support equipment and facilities and to use them in the same manner as they currently operate.

The only alternative to deploying the Viper considered was the alternative of taking no action. This would mean that the Air Force would continue to use the aging, more costly, and more difficult to produce AIM-9. This alternative is in conflict with stated DOD policy, which seeks the most effective weapons systems for its combat forces.

Potential impacts to the natural and human environments resulting from the implementation of the Proposed Action would be minor. Potential impacts to the natural and human environments considered in this assessment related to air quality, water quality, noise, land use, hazardous materials/waste management, health and safety, cultural resources, infrastructure, and socioeconomics. A brief summary of these resources follows.

Air Quality - Implementation of the Proposed Action would produce no impact upon the air quality in the vicinity of the recycling facility, or of the disposal site of unrecycled missiles.

Water Quality - If the Proposed Action were implemented, there would be no effect upon water quality in the vicinity of the recycling facility, or of the disposal site of unrecycled missiles. HX-4000 does not react or degrade with immersion to water, so spent missiles fired over water will produce no impacts on the body of water they are left in (Frank;1993).

Noise - The retirement of the Viper missile will have no impact on current environmental noise levels. Occupational Health and Safety Administration (OSHA) regulations will apply to the production facility.

Land Use - The retirement of Viper missiles would require no additional land use, compared to current missile retirement.

Hazardous Materials/Waste Management - Retirement of the Viper Missile will require no hazardous materials and produce no hazardous waste. The majority of the retired missiles will be recycled. The unrecovered missiles and missile components will degrade in a manner similar to the aluminum AIM-9. No significant impacts would occur in this area due to the Proposed Action.

Health and Safety - Recycling facilities which will be used for the Viper are already subject to OSHA regulations. Degrading HX-4000 produces no known health risks to humans, animals, or plant life. HX-4000 is an inert, non-flammable, plastic. The Viper will be used in the same manner as the AIM-9 and will follow the same safety regulations. Overall, no health and safety impacts would be expected.

Cultural Resources - The retirement of the Viper missile would take place at existing disassembly and recycling facilities. The change from AIM-9s to Vipers will not significantly affect the size or nature of facility operations. All Viper test firings and ground operations will be conducted on restricted government facilities, designed expressly for this purpose. No impacts to cultural resources would occur.

Infrastructure - Current infrastructure is adequate to accommodate the change from the AIM-9 to the Viper. The Viper will use existing recycling facilities and the same range and depot facilities as the AIM-9 and will use them in the same manner.

Socioeconomics - The conversion from metal to polymer plastic missiles should cause no significant socioeconomic impact. The salvage value of aluminum is higher than HX-4000 and is likely to remain so. Ordinance disposal and depot units which sell aluminum AIM-9 components may lose this money with the conversion from aluminum to HX-4000 components (Hopper;1993). No other impacts are anticipated due to this change.

1.0 Purpose and Need for the Proposed Action

The National Environmental Policy Act (NEPA), the Council on Environmental Quality (CEQ) regulations implementing the Act (40 Code of Federal Regulations [CFR] 1500-1508), Department of Defense (DOD) Directive 6050.1, and Air Force Regulation (AFR) 19-2, which implements these laws and regulations, direct that DOD and U.S. Air Force (USAF) officials consider environmental consequences when authorizing or approving federal actions. Accordingly, this Environmental Assessment (EA) analyzes the potential environmental consequences of the proposed conversion from the AIM-9 air to air missiles to the Viper air to air missile.

The USAF continues to improve its air to air combat forces through the introduction of new technologies and materials. The use of Liquid Crystalline Polymers (LCP) in the air frames and rocket motor casings has produced significant improvements in missile air speed, maneuverability, and range. Additionally, the LCP missiles cost half of what current AIM-9 missiles cost to produce and will require significantly fewer people and procedures in maintenance and handling.

The objective of the Proposed Action is to improve the performance of air to air combat weapons systems by deploying Viper missiles constructed of LCP materials to replace all metal AIM-9 missiles. The Proposed Action addressed in this assessment is the retirement of the Viper missiles.

This EA describes and addresses the potential environmental impacts of retiring and disposing of Viper air to air missiles. The EA also presents mitigation measures to reduce or eliminate environmental impacts. These measures would be incorporated into disassembly and disposal procedures. The EA also evaluates potential alternatives to the Proposed Action, keeping in mind their impact on the project's objectives and mission requirements.

In accordance with AFR 19-2 and the CEQ regulations, the scope of analysis presented in this assessment is defined by the potential range of environmental impacts that would result from implementation of the Proposed Action. Evaluation indicated no adverse long or short term impacts to physical resources.

2.0 Description of the Proposed Action and Alternatives

2.1 Description of the Proposed Action

The USAF is proposing to convert from deploying AIM-9 air to air missiles, constructed of metal alloys, to Viper missiles made from LCP plastic materials. When the missile has completed its usefulness, it will be disposed of in one of three ways: fired from a weapons platform, disassembled and recycled, or disassembled and buried in a landfill.

2.1.1 Characteristics of the Materials Involved

Manufactured by the DuPont Chemical Corporation, HX-4000 is a thermotropic LCP. (Thermotropic LCPs exhibit crystalline characteristics in the melted state, which differentiates them from lyotropes, which display this characteristics in solution). Thermotropic LCPs are suited for use in high-stress, high temperature applications because they exhibit the phenomenon of annealing, when subjected to a long duration temperature cycle, after which they will behave as a thermoset (Chew:2).

2.1.2 Retirement Operations

If the proposed conversion is enacted, the facilities currently used for disassembling and disposing of AIM-9 missiles would be used for the Viper missiles. These facilities will operate in the same manner as they are currently for the AIM-9.

2.1.3 Material Safety

HX-4000 and other similar LCP materials are non-toxic, non-reactive, plastics which do not conduct electricity. LCPs pose no known threats due to prolonged exposure, inhalation, or ingestion (Du Pont;4).

2.1.4 Process Safety

The Viper missile will be retired in the same manner as the AIM-9. The Viper has been designed to use AIM-9 support equipment and will follow existing AIM-9 disassembly and disposal procedures. All AIM-9 safety procedures will remain in effect (GSE;4-59).

2.1.5 Personnel Summary

The proposed action would require the same number of depot personnel to disassemble the Viper as are currently required for the AIM-9. Salvaged materials will be recycled by commercial contractors.

2.1.6 Construction

The conversion to LCP missiles would require no construction. Existing depot maintenance facilities have sufficient capacity to accommodate the Vipers (Sturm;1993).

2.2 No Action Alternative

If the proposed conversion does not occur, the AIM-9 missile will remain the weapon system in use. The AIM-9 will be disassembled at its current depot facilities and launched from its current platforms over approved weapons ranges. Salvaged metal components from the AIM-9 will continue to be recycled commercially.

3.0 Affected Environment

All areas affected by the change from AIM-9 to Viper air-to-air missiles will be existing missile maintenance depots and test range facilities. These facilities will have met or exceeded state and federal environmental standards and will not be significantly altered by the proposed action. Environmental Assessments for these facilities will address the affects they have on the surrounding environment.

4.0 Environmental Consequences

This section presents the results of the analysis of the potential environmental effects upon system retirement of implementing the proposed conversion from metal to polymer plastic air-to-air missiles. Changes to the natural and human environments which might result from the Proposed Action were evaluated relative to the affected environment. Possible direct and indirect effects were assessed both qualitatively and quantitatively, considering both short and long term effects. The potential for significant environmental consequences was evaluated using the intensity and context considerations defined in CEQ regulations for implementing the procedural provisions of NEPA (USAF 1986;1508.27).

Cumulative impacts result from "the incremental impact of the action when added to other past, present, and future actions regardless of what agency undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time" (CRS;13). If the maintenance facility is used exclusively for activities similar to the Viper maintenance, the Proposed Action should not contribute to any long term impacts.

4.1 Direct and Indirect Affects and Their Significance

4.1.1 Air Quality

Conversion from the AIM-9 to the Viper should yield no change in the air quality of the area surrounding the maintenance depot and test facilities. No other procedures involving Viper disassembly and recycling should effect the air quality differently from effects currently experienced in the use of the AIM-9 (Sturm;1993).

Implementation of the Proposed Action would result in no change to the air quality of the depot facility, or the range where the missile will be fired (Hopper;1993).

4.1.2 Wastes

The disassembly and recycling of the Viper should produce no waste materials. All LCP components will be completely recyclable. All non-LCP components, such as the guidance and control system electronics, will be recycled or disposed of in the same manner as at present with the AIM-9 (Rusek;1993).

4.1.3 Water Resources

Both the Proposed Action and the No-Action alternative will make no changes to current water resources. Current maintenance facilities meet all local, state, and federal water protection standards (Kathan;3).

4.1.4 Noise - Noise levels for both the disassembly of the Viper and AIM-9 will remain the same as they are under current maintenance conditions, if the Proposed Action or No-Action alternative are adopted, respectively. Current maintenance facilities meet state and federal OSHA standards (Kathan;2).

4.1.5 Land Use - Both the Proposed Action and the No-Action alternative would use existing depot and range facilities without additional land use (GSE;4-59).

4.1.6 Infrastructure - Current infrastructure is adequate to handle the Proposed Action. No additional facilities will be required (GSE;4-60). The current infrastructure is also adequate to accommodate the No-Action alternative.

4.1.7 Hazardous Materials/Waste Management - No hazardous materials/waste are expected to be produced from the proposed action. Transportation, disassembly, and recycling of the Viper will neither require, nor produce any such materials (Frank;1993). Adoption of the No-Action alternative will lead to no changes in the current procedures.

4.1.8 Health and Safety - HX-4000 is an inert plastic which poses no threat if inhaled or placed in contact with body tissue (Du Pont;3). The control of any potential impacts would be based on established procedures and equipment specified by OSHA regulations. The No-Action alternative would make no changes to existing facilities, materials, and procedures, and would produce no additional health and safety hazards.

4.1.9 Biological Resources - Implementation of the Proposed Action would result in no change in available habitat to biological species around the depot facility or the weapons range (Hopper;1993). The Viper will require no additional land or water use over and above AIM-9 retirement. Federally or state threatened or endangered species will face no increase in threats due to the use of the Viper. Under the No-Action alternative, use of the AIM-9 will continue in existing facilities already approved for its use.

4.1.10 Socioeconomics - Conversion from AIM-9 to Viper missiles will have a minor impact upon employment in the recycling of salvaged missile components. Commercial recycling of salvaged AIM-9 aluminum is conducted by both maintenance depots and ranges (Hopper;1993). Conversion to the Viper will reduce the amount of aluminum available for recycling. The LCP material salvaged from the Viper will also be recycled, but the process of reconstituting LCP is very limited commercially. Salvaged LCP will be recycled at the production facility and the volume of business between aluminum recycling companies and the depots and ranges. The salvage price of LCP is expected to be substantially less than aluminum (Frank;1993).

No significant adverse social or economic effects would be associated with the proposed conversion. The conversion would result in only minor changes in the number of operational and maintenance personnel and thus would not influence local trends in population growth and distribution. The conversion might produce some small economic benefits to injection molding manufacturers in the area, who might produce some replacement parts for the Viper (Stoddard;1993).

<u>4.1.11 Cultural Resources</u> - The use of the Viper will have no effect upon known historic or cultural resources. All maintenance facilities and ranges will be used in the same manner as they are presently used, with no expansion required. No additional disturbance to cultural resources would result from the No-Action alternative.

4.2 Relationship of Proposed Action to Objectives of Land Use Plans, Policies, and Controls

The proposed missile conversion is not expected to adversely affect the overall objectives of current land use plans, policies, and controls of areas adjacent to Air Force Maintenance Depots or Test Ranges.

Appendix E

Calculation of Model Scores

The translation of data gathered from questioning of the system users and manufacturers into the scores for the model was accomplished by comparing the data to the standards described in section 3.

As an example of this process, this section will explain the translation of data gathered on the production of the AIM-9 missile into model scores.

Data on the production of the AIM-9 missile was gathered from the office of Environmental Compliance of the Hercules Manufacturing Company, using the questions listed in section 3.6. The responses to these questions were then converted into scores in the manner described.

In response to the questions listed in section 3.6, the Hercules manufacturing Company reported the following waste products for AIM-9 production.

In cases where the substance is recycled, the Hercules Manufacturing Company reported this was due to a corporate commitment to environmental responsibility. Hercules recycles whenever this is technically and financially feasible. Air emission of wastes occurs only when recapture and recycle of the substance is not technically or economically feasible. Burning of wastes occurs only when other methods of disposal are not practical. All waste disposal is conducted in accordance with all local, state, and federal statutes and regulations.

Table E-1; AIM-9 Production Waste Products

Substance	Reportable Quantity (In Pounds)	Amount of Waste Produced (In Pounds)	Estimated Cost of 50% Spill Remediation (In Dollars)	How Disposed of
Oil	1,000	1.5	100.00	Recycled
Paint	100	57.0	100.00	Recycled
Methylene Chloride	100	44.3	15,000.00	Recycled
Waste Fixer Solution	100	525.0	12,000.00	Recycled
Solvent Contaminated Rags	10	3,120.0	1,500.00	Burned
Aluminzed Propellant	1,000	35,148.0	15,000.00	Burned
Solvent (Ammonium Picrate)	10	3,089.0	12,000.00	Burned
TCA	100	7,638.0	17,000.00	Burned
Dichloromethane	1,000	2,319.0	12,000.00	Air Emission
1,1,1 Trichloroethane	100	3,568.5	150,000.00	Air Emission
Acetone	10	10.5	1,500.00	Recycled
MEK	10	151.5	2,500.00	Air Emission
Isopropyl Alcohol	1,000	382.5	1,000.00	Recycled
Xylene	1,000	652.5	1,500.00	Air Emission
Toluene	1,000	270.0	1,200.00	Air Emission
Aluminum	1,000	10,000.0	2,000.00	Recycled
Trichloroethylene	5,000	1,681.5	12,000.00	Air Emission

The Office of Environmental Compliance for the Hercules Manufacturing Company provided the following additional information on these substances to aid in their conversion into scores for the model:

Oil : Manufacture of the AIM-9 produces 2,250 pounds of waste oil. With a reportable quantity of 1,000 pounds, this amount yields a score of 2.25 times RQ. An accidental spill of one half of this amount (1,125 pounds) in the manufacturing facility where it is used was estimated to cost approximately $5,000 to clean up. This cost corresponds to a model score of 1 in the cost area. Oil is rated as a score of 1 on the Sax Persistence Scale. Adding 1 to this yields a score of 2. This waste oil is disposed of through recycling. Recycling of waste oil is relatively easy, and is done at small expense. This places oil in the third category on the recyclability scale.

Paint (xylenol, toloul) : Manufacture of the AIM-9 produces 57 pounds of waste paint. With a reportable quantity of 100 pounds, this amount yields a score of 0.57 times RQ. An accidental spill of one half of this amount (28.5 pounds) in the manufacturing facility where it is used was estimated to cost approximately $500 to clean up. This cost corresponds to a model score of 1 in the cost area. Paint is rated as a score of 1 on the Sax Persistence Scale. Adding 1 to this yields a score of 2. This waste paint is disposed of through recycling. Recycling of waste paint is relatively difficult, and is done at some expense. This places paint in the second category on the recyclability scale.

Methylene Chloride : Manufacture of the AIM-9 produces 1,475 pounds of waste methylene chloride. With a reportable quantity of 100 pounds, this amount yields a score of 14.75 times RQ. An accidental spill of one half of this amount (737.5 pounds) in the manufacturing facility where it is used was estimated to cost approximately $12,000 to clean up. This cost corresponds to a model score of 2 in the cost area. Methylene Chloride is rated as a score of 2 on the Sax Persistence Scale. Adding 1 to this yields a score of 3. This waste Methylene chloride is disposed of through recycling. Recycling of waste Methylene chloride is relatively difficult, and is done at some expense. This places Methylene chloride in the second category on the recyclability scale.

Fixer Solution : Manufacture of the AIM-9 produces 525 pounds of waste fixer solution. With a reportable quantity of 100 pounds, this amount yields a score of 5.25 times RQ. An accidental spill of one half of this amount (262.5 pounds) in the manufacturing facility where it is used was estimated to cost approximately $5,000 to clean up. This cost corresponds to a model score of 2 in the cost area. Fixer solution is rated as a score of 1 on the Sax Persistence Scale. Adding 1 to this yields a score of 2. This fixer solution is disposed of through recycling. Recycling of waste fixer solution is relatively difficult, and is done at some expense. This places fixer solution in the second category on the recyclability scale.

Rags : Manufacture of the AIM-9 produces 1,700 pounds of waste rags contaminated with solvent and oil. These rags assume the reportable quantity of the most hazardous substance absorbed by them. This is the solvent, with an RQ of 10 pounds, this amount yields a score of times RQ. An accidental spill of one half of this amount (850 pounds) in the manufacturing facility where it is used was estimated to cost approximately $2,500 to clean up. This cost corresponds to a model score of 1 in the cost area. The rags assume the persistence of the most persistent substance absorbed by them. This is the paint, rated as a score of 1 on the Sax Persistence Scale. Adding 1 to this yields a score of 2. These rags are disposed of through burning. Recycling of contaminated rags is difficult and expensive to the point of not being practical. The rags would need to be thoroughly cleaned and the contaminants and cleaning medium disposed of. It is much more practical for the manufacturer to burn the rags. This places the rags in the first category on the recyclability scale.

Solvent (Ammonium Picrate) : Manufacture of the AIM-9 produces 2,495 pounds of waste cleaning solvent. With a reportable quantity of 10 pounds, this amount yields a score of 308.9 times RQ. An accidental spill of one half of this amount (1,247.5 pounds) in the manufacturing facility where it is used was estimated to cost approximately $12,000 to clean up. This cost corresponds to a model score of 2 in the cost area. Solvent is rated as a score of 0 on the Sax Persistence Scale. Adding 1 to this yields a score of 1. This waste solvent is disposed of through burning. Recycling of solvent is difficult and would require separating the solvent from the contaminants it has dissolved. Such a process would be too expensive for the manufacturer to pursue. This places solvent in the first category on the recyclability scale.

Propellant: Manufacture of the AIM-9 produces 25,000 pounds of waste aluminized rocket propellant. With a reportable quantity of 100 pounds, this amount yields a score of 351.5 times RQ. An accidental spill of one half of this amount (12,500 pounds) in the manufacturing facility where it is used was estimated to cost approximately $25,000 to clean up. This cost is largely due to the extreme flammability of the propellant and corresponds to a model score of 2 in the cost area. Propellant is rated as a score of 0 on the Sax Persistence Scale. Adding 1 to this yields a score of 1. This waste propellant is disposed of through burning. Recycling of waste propellant is not technically feasible, as contaminated propellant might cause the failure of the rocket it is used in. This places the propellant in the first category on the recyclability scale.

TCA : Manufacture of the AIM-9 produces 7,638 pounds of waste TCA. With a reportable quantity of 100 pounds, this amount yields a score of 76.4 times RQ. An accidental spill of one half of this amount (3,819.0 pounds) in the manufacturing facility where it is used was estimated to cost approximately $15,000 to clean up. This cost corresponds to a model score of 2 in the cost area. TCA is rated as a score of 1 on the Sax Persistence Scale. Adding 1 to this yields a score of 2. This waste TCA is disposed of through burning. Recycling of waste TCA is prohibitively difficult and expensive. This places TCA in the first category on the recyclability scale.

Dichloromethane : Manufacture of the AIM-9 produces 2,319 pounds of waste Dichloromethane. With a reportable quantity of 1,000 pounds, this amount yields a score of 2.3 times RQ. An accidental spill of one half of this amount (1,159.5 pounds) in the manufacturing facility where it is used was estimated to cost approximately $12,000 to clean up. This cost corresponds to a model score of 2 in the cost area. Dichloromethane is rated as a score of 1 on the Sax Persistence Scale. Adding 1 to this yields a score of 2. This waste dichloromethane is disposed of through release as an airborne emission. Recycling of waste dichloromethane is prohibitively difficult and expensive. This places dichloromethane in the first category on the recyclability scale.

1,1,1 Trichloroethane : Manufacture of the AIM-9 produces 3568 pounds of waste 1,1,1 trichloroethane. With a reportable quantity of 100 pounds, this amount yields a score of 35.7 times RQ. An accidental spill of one half of this amount (1,748 pounds) in the manufacturing facility where it is used was estimated to cost approximately $25,000 to clean up. This cost corresponds to a model score of 2 in the cost area. 1,1,1 trichloroethane is rated as a score of 2 on the Sax Persistence Scale. Adding 1 to this yields a score of 3. This waste 1,1,1 trichloroethane is disposed of through release into the atmosphere as an airborne emission. Recycling of waste trichloroethane is prohibitively difficult and expensive. This places trichloroethane in the first category on the recyclability scale.

Trichloroethylene : Manufacture of the AIM-9 produces 1,682 pounds of waste trichloroethylene. With a reportable quantity of 1,000 pounds, this amount yields a score of 1.7 times RQ. An accidental spill of one half of this amount (841 pounds) in the manufacturing facility where it is used was estimated to cost approximately $10,000 to clean up. This cost corresponds to a model score of 2 in the cost area. Trichloroethylene is rated as a score of 0 on the Sax Persistence Scale. Adding 1 to this yields a score of 1. This waste trichloroethylene is disposed of through release into the atmosphere as an airborne emission. Recycling of waste trichloroethylene is relatively difficult, and is done at some expense. This places trichloroethylene in the second category on the recyclability scale.

Acetone : Manufacture of the AIM-9 produces 10.5 pounds of waste acetone. With a reportable quantity of 10 pounds, this amount yields a score of 1.1 times RQ. An accidental spill of one half of this amount (5 pounds) in the manufacturing facility where it is used was estimated to cost approximately $100 to clean up. This cost corresponds to a model score of 1 in the cost area. Acetone is rated as a score of 0 on the Sax Persistence Scale. Adding 1 to this yields a score of 1. This waste acetone is disposed of through recycling. Recycling of waste acetone is relatively easy, and is done at small expense. This places acetone in the third category on the recyclability scale.

Methyl Ethyl Ketone (MEK) : Manufacture of the AIM-9 produces 152 pounds of MEK. With a reportable quantity of 10 pounds, this amount yields a score of 15.2 times RQ. An accidental spill of one half of this amount (126 pounds) in the manufacturing facility where it is used was estimated to cost approximately $12,000 to clean up. This cost corresponds to a model score of 2 in the cost area. MEK is rated as a score of 2 on the Sax Persistence Scale. Adding 1 to this yields a score of 3. This waste MEK is disposed of through release into the atmosphere as an airborne emission. Recycling of waste MEK is prohibitively difficult and expensive. This places MEK in the first category on the recyclability scale.

Toluene : Manufacture of the AIM-9 produces 270 pounds of waste toluene. With a reportable quantity of 1,000 pounds, this amount yields a score of .3 times RQ. An accidental spill of one half of this amount (165 pounds) in the manufacturing facility where it is used was estimated to cost approximately $500 to clean up. This cost corresponds to a model score of 1 in the cost area. Toluene is rated as a score of 0 on the Sax Persistence Scale. Adding 1 to this yields a score of 1. This waste toluene is disposed of through release into the atmosphere as an airborne emission. Recycling of waste toluene is relatively difficult, and is done at some expense. This places toluene in the second category on the recyclability scale.

Isopropyl Alcohol : Manufacture of the AIM-9 produces 382 pounds of waste isopropyl alcohol. With a reportable quantity of 1,000 pounds, this amount yields a score of .4 times RQ. An accidental spill of one half of this amount (191 pounds) in the manufacturing facility where it is used was estimated to cost approximately $200 to clean up. This cost corresponds to a model score of 1 in the cost area. Isopropyl alcohol is rated as a score of 0 on the Sax Persistence Scale. Adding 1 to this yields a score of 1. This waste isopropyl alcohol is disposed of through recycling. Recycling of waste isopropyl alcohol is relatively easy, and is done at small expense. This places isopropyl alcohol in the third category on the recyclability scale.

Xylene : Manufacture of the AIM-9 produces 652 pounds of waste xylene. With a reportable quantity of 1,000 pounds, this amount yields a score of .7 times RQ. An accidental spill of one half of this amount (326 pounds) in the manufacturing facility where it is used was estimated to cost approximately $5,000 to clean up. This cost corresponds to a model score of 1 in the cost area. Xylene is rated as a score of 1 on the Sax Persistence Scale. Adding 1 to this yields a score of 2. This waste xylene is disposed of through release into the atmosphere as an airborne emission. Recycling of waste xylene is relatively easy, and is done at small expense. This places xylene in the second category on the recyclability scale.

Aluminum : Manufacture of the AIM-9 produces 10,000 pounds of waste aluminum. With an estimated reportable quantity of 5,000 pounds, this amount yields a score of 2 times RQ. An accidental spill of one half of this amount (5,000 pounds) in the manufacturing facility where it is used was estimated to cost approximately $500 to clean up. This cost corresponds to a model score of 1 in the cost area. Aluminum is rated as a score of 3 on the Sax Persistence Scale. Adding 1 to this yields a score of 4. This waste aluminum is disposed of through recycling. Recycling of waste aluminum is easy and the metal may be sold as scrap, generating income. This places aluminum in the fourth category on the recyclability scale.

These scorings were used to generate the model scores shown in Appendix A. All other systems and processes were scored in a similar manner.

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Vita

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
21 March 1995

3. REPORT TYPE AND DATES COVERED
Masters

4. TITLE AND SUBTITLE
A Decision Model for Environmental Assessment of Process Waste Products

5. FUNDING NUMBERS

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AFIT/ENY
Dr. Paul King
WPAFB,OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GEE/ENV/95M-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Sandia National Laboratories
Energy and Environmental Division
Dept. 6613
Box 5800
Albuquerque, NM 87185-0746

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Environmental managers must compare the potential impacts of waste products when deciding upon courses of action. The estimation and comparison of these impacts is a subjective process, and few methods of comprehensive, quantitative comparison of waste products currently exist.

The intent of this study is to develop a decision methodology to evaluate the environmental impacts of waste products and to score them for comparison. The method will follow established system design principles and incorporate significant characteristics of the waste material. Scores derived to represent the environmental impacts of materials will then be analyzed employing statistical and probabilistic methods to assess decision risk and the need for more precise information.

As an example of the method's use, it and traditional Environmental assessment (EA) methods are used to evaluate the replacement of the AIM-9 air-to-air missile with a thermoplastic missile.

Environmental Assessments of missile production, operations and maintenance, and retirement are presented. Both evaluation methods determine the thermoplastic missile to have a less negative impact than the AIM-9 in all stages. The decision methodology allows for better standardization of the analysis, quantification of the impacts, and sensitivity analysis of the characteristics of the waste materials.

14. SUBJECT TERMS

15. NUMBER OF PAGES
138

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited